COMBUSTION

1933

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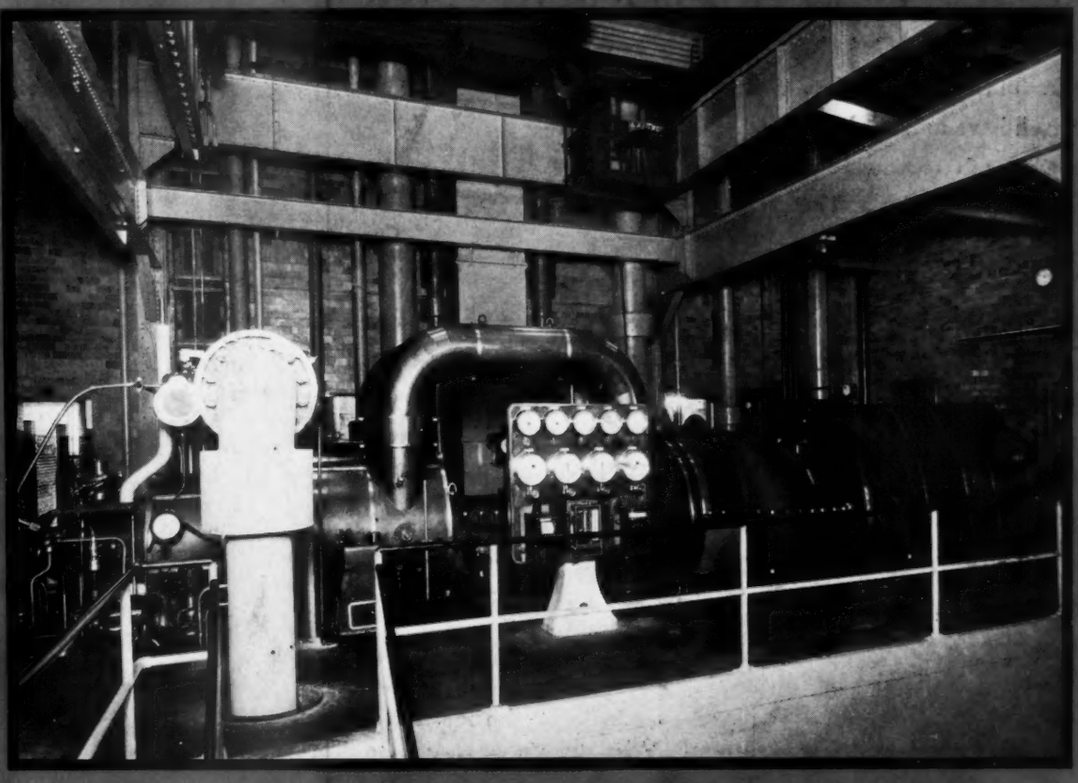

10,000-kw. turbine operating at 1000 fahr., Delray Power House No. 3, Detroit Edison Company

High-Temperature Steam Experience at Detroit

•

Supersaturated Steam

POLICIES

NUMBER TWO

of A Series of Advertisements Outlining Policies of

COMBUSTION ENGINEERING COMPANY • INC

Number One of this series outlined those *sales* policies of Combustion Engineering which have a direct bearing on its relations with customers. This and succeeding advertisements will cover similar policies with respect to *engineering, manufacturing* and *service.*

ENGINEERING POLICY

As designers and manufacturers of equipment, the proper selection and application of which involves complex engineering problems and the exercise of judgment based on experience, Combustion Engineering offers a complete engineering advisory service. This service complements the work of its customer's consulting or staff engineers by placing at their disposal the accumulated knowledge of an organization which has specialized in the fields of combustion and steam generation for many years and which has been responsible for a number of the most notable and successful boiler plant installations in the country.

When desired, this service begins with the analysis of plant conditions and recommendations showing how those conditions may be met most economically and efficiently. Subsequent steps include the preparation of general layout drawings to develop the most advantageous arrangement of the equipment to be installed with respect to existing equipment, or in the case of complete steam generating units, the best overall design.

All recommendations and designs are developed in cooperation with the customer's consulting or staff engineers, and are directed toward the objective of obtaining the most economical results for the particular fuel and load conditions to be met.

This engineering service is unbiased with respect to type of equipment since Combustion Engineering products include boilers, stokers, pulverized fuel systems and heat recovery equipment in a range of types and sizes adequate for the load and fuel conditions of any plant. It assures the purchaser of a thoroughly modern installation which will be properly adapted to his requirements and which will equal or exceed the results expected.

COMBUSTION ENGINEERING PRODUCTS

•

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C-E Box Header Boilers
C-E Bent Tube Boilers
C-E H.R.T. Boilers
C-E Electric Boilers

STOKERS

C-E Multiple Retort Stoker
Type E Underfeed Stoker
Type E Stoker-Unit (*for small boilers*)
Type H Stoker (*for industrial furnaces*)
Coxe Traveling Grate Stoker
Green Chain Grate Stoker (*natural draft*)
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Lopulco Storage System
Lopulco Direct-Fired System
Raymond Pulverizing Mills

WATER-COOLED FURNACES

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Lopulco Water Screen
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Coordinated designs comprising any combination of boiler and firing equipment and
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(*a standard unit for small plants*)

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(*plate and tubular types*)
C-E Economizer
Quinn Oil Burners
Grieve Grates
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C-E Ash Hopper

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COMBUSTION

VOLUME FIVE • NUMBER FIVE

CONTENTS

FOR NOVEMBER 1933

FEATURE ARTICLES

Plate-Type Air Heater Development and Present Status in the United States — *by W. S. Patterson* 7

High-Temperature Steam Experience at Detroit — *by P. W. Thompson and R. M. Van Duzer, Jr.* ... 13

Supersaturated Steam — *by John I. Yellott, Jr.* 22

Patents, Part XIII — *by George Ramsey* 29

Code of Fair Competition for the Boiler Manufacturing Industry 34

EDITORIALS

High-Temperature Experience at Detroit 5

The Boiler Industry Code 5

A.S.M.E. Papers Available 5

DEPARTMENTS

New Equipment—*Recording Flow Meter, Improved Bucket Trap, New Two Position Motor Operated Controller, Large Volume Trap* 37

Equipment Sales—Boiler, Stoker and Pulverized Fuel 39

Advertisers in This Issue 40

H. STUART ACHESON, *General Representative* — **CHARLES McDONOUGH**, *Editor* — **F. H. ROSENCRANTS**, *Associate Editor*

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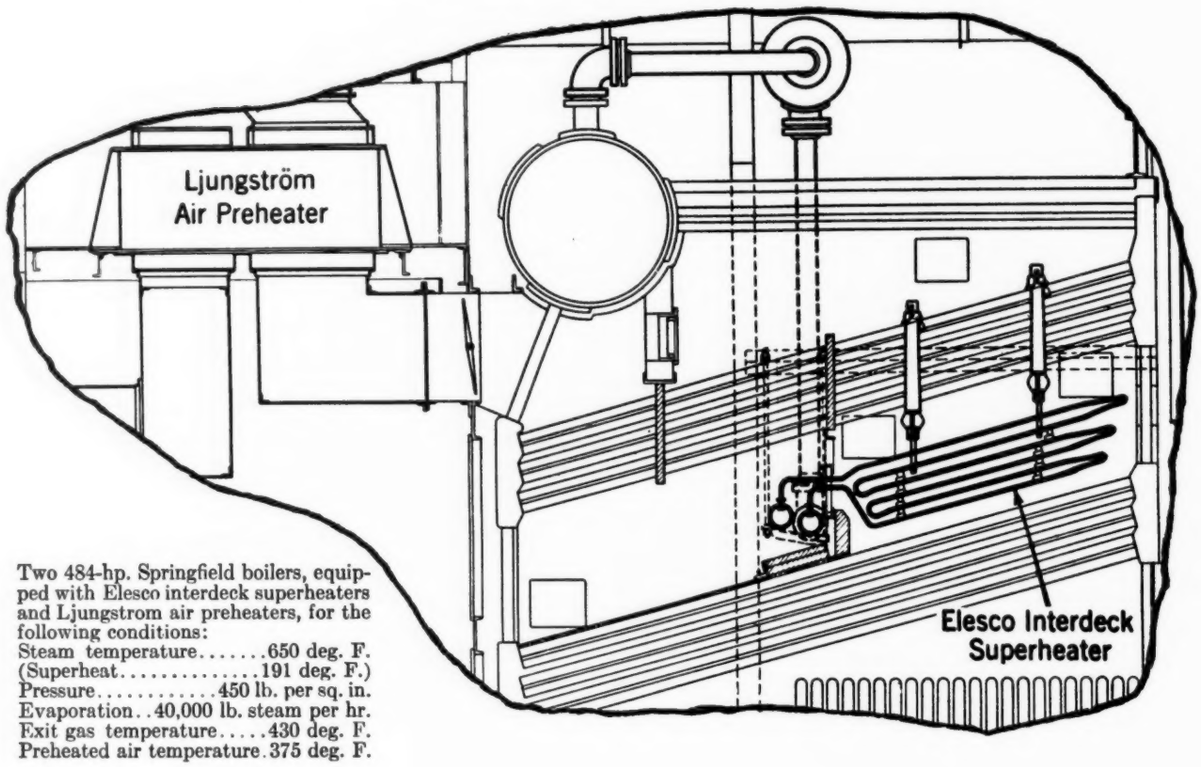

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Pressure.....450 lb. per sq. in.
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EDITORIAL

High-Temperature Experience at Detroit

FOR some years power-plant designers have been divided in their opinions as between very high steam pressures with moderate temperatures and reheat and the employment of very high temperatures with moderate pressures. There has been ample experience with the former combination, but it was contended by many that the high temperatures, while thermodynamically desirable, would entail operating and maintenance difficulties because of the inability of existing materials to withstand such conditions. Hence when the Detroit Edison Company announced its decision to install a unit to operate at one thousand fahrenheit, the outcome of this pioneer step was awaited with keen interest.

The Detroit installation has now been in service since 1929 and the paper by Messrs. Thompson and Van Duzer is an invaluable report of the operating experience, especially as concerns the behavior of the various materials employed. The initial superheater installation at Trenton Channel has been in service for more than twenty-three thousand hours, over twenty-one thousand of which has been at temperatures ranging from one thousand to eleven hundred fahrenheit. The ten-thousand-kilowatt unit at Delray has operated over eleven thousand hours of which nearly eight thousand has been at one thousand fahrenheit.

Only minor difficulties have been experienced with the superheater and turbine; in fact, such as might be expected in tuning up any new installation. Of course, the equipment has received very close attention. Some troubles were encountered with pipe joints, but creep has not been as marked as was anticipated, which leads to the conclusion that higher design stresses might have been selected with safety.

Despite this favorable experience there is some doubt as to the present commercial economy of an installation operating at these temperatures because of the high cost of the materials involved. With the knowledge gained through this experience at Detroit, supplemented by constant research in the field of metals and alloys, it is possible that costs may be brought down to where the thermal advantages of high temperature can be utilized without greatly increasing the initial investment.

The Boiler Industry Code

IN ORDER that those negotiating purchases or preparing specifications for boilers, fuel-burning equipment and certain heat-recovery apparatus may be conversant with the new order of things, the recently enacted N.R.A. Code, applicable to such equipment, is reproduced in full in this issue.

While much of the Code deals with conditions of production, the section on "fair practices" is of special concern to the purchaser. As in many other lines, conditions during the past three years led to certain practices being dictated by purchasers that were harmful to the industry and of questionable benefit to themselves. The Code attempts to rectify these abuses. Some purchasers may chafe at certain of its provisions until the aims and fair intent of the code are fully appreciated. It represents a composite viewpoint of the industry and aims to place the manufacturers on an equal footing. Thus, in the competition for new business special emphasis is likely to be placed on quality of product, past performance and engineering background.

Provision has been made for modifying the Code if, after a fair trial, any of its provisions are found to need revision. In the meantime, its application should be approached with an open mind and a spirit of cooperation by both manufacturers and purchasers, for in the final analysis they have a common interest.

Supplementary Codes are now being formulated to cover further trade practices and policies for different branches of the industry which will apply only to those branches such as water-tube boilers, horizontal return-tubular boilers, pulverizing equipment, stokers, superheaters and other equipment referred to in the basic code.

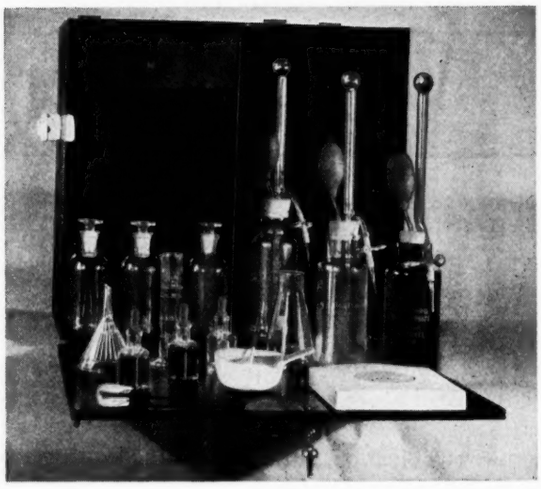
A.S.M.E. Papers Available

DUE to the restricted publication activities of the A.S.M.E. it will be impossible for the Society to preprint for distribution other than very brief abstracts of the Annual Meeting papers. The program is especially good this year and it is unfortunate that all the papers cannot be printed in full.

To ameliorate this situation, insofar as concerns papers of interest to steam-plant men, COMBUSTION has agreed to cooperate with the A.S.M.E. by publishing in full a number of the papers of the fuels, power, feedwaters and heat-transfer sessions; others will appear in extended abstract. Certain of these papers are included in the November issue and the December issue will be devoted largely to this purpose. Furthermore, for the convenience of those in attendance and as an aid to discussors COMBUSTION is planning to furnish preprints of the papers for distribution at the sessions. It will be recalled that a similar plan was carried out effectively at the meeting in Chicago last June.

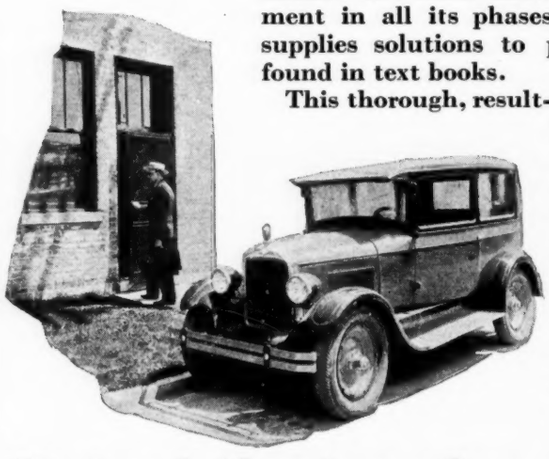
Nalco System

Water Treatment is under constant control



MOST water supplies, especially surface waters, vary in quality from season to season, from day to day, or, in some cases, even more frequently. The latter, fortunately, are rare. A treatment based on tests at any one time may be quite inexact at other times. An important feature of the Nalco System is the provision for constant control of treatment to adapt it to the condition of the water at all times.

There are three phases to this control of treatment. First, the engineer in charge has a simple testing kit to make daily checks on his water supply as a basis for modifying the amount of treatment needed. Report forms carry a record of these tests to the Nalco service department. Second, a Nalco field man periodically checks conditions with the engineer to keep treating results up to the highest standards. Third, unusual problems which occasionally arise have the immediate attention of men on the general staff who are in the first rank of water treating engineers in the country. They have pioneered practice which has now become standard and they are continually pushing ahead into a fuller knowledge of water treatment in all its phases. Their experience supplies solutions to problems not even found in text books.



This thorough, result-producing control is yours at no extra cost. The Nalco System is economical. It saves money from the beginning—often in large amounts. The first step to such results is a free survey of your water conditions. Ask for it.

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2

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3

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4

The method of application of the treating chemicals is specified by men who have pioneered new standards of results in water treatment.

5

A simple testing kit and report forms are made available to the engineer in charge of the plant for detecting daily or seasonal changes in water or in the results of treatment.

6

The field men periodically check conditions with the engineers and counsel regarding any improvements in practice.

7

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8

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Plate-Type Air Heater Development and Present Status in the United States

By W. S. PATTERSON
Combustion Engineering Company, Inc.

The air preheater, although employed in marine work at an early date, was first applied to land practice in the United States in 1881. In England the plate-type had its first application through a desire to burn small screenings on mechanical stokers. Low steam pressures and consequent low exit gas temperatures provided little incentive for heat recovery, hence the use of air preheaters lagged until the era of high steam pressures about 1922. The extensive use of water walls and pulverized coal further stimulated employment of air preheaters to their present status. The outstanding features of several well-known makes of the plate-type preheater are discussed.

Early Air Preheaters

THE use of air preheaters to improve the performance of steam generating units appears to have originated in marine practice over fifty years ago. The heaters of those days were nearly all of the tubular type employing various tube arrangements such as vertical or horizontal banks of short or long tubes sometimes with the gases passing through the tubes and sometimes the air. Some of them were more or less standardized products of manufacture adapted to fit a particular type of boiler but many were merely makeshift arrangements.

The first application of air preheaters in land practice in this country appears to have been about 1881 at a plant of the Pacific Mills in Lawrence, Mass. The air heater, then variously referred to as a heat abstractor, warm-blast apparatus, or hot-draft apparatus, was in this particular instance applied to a horizontal return-tubular boiler and consisted of two horizontal banks of 2-in. diameter lap-welded tubes through which the hot gases passed. Surrounding each 2-in. tube was a 3-in. tube, concentrically arranged but somewhat shorter to allow the air to be passed through the annular space between the inner and outer tubes. It is interesting to read that after extended experiment this apparatus was found to be incapable of reducing the gas temperature below 160 fahr. This performance seems to have disappointed the builders, so another heater was designed for an adjacent boiler consisting of 2-in. tubes arranged one inch apart through which spaces the air made several passes across the tube bank. Reported tests indicate that this second heater produced a gas temperature drop about five degrees greater than the first and gave 12.5 points better efficiency than a similar unit operating without an air heater.[1] After three years' operation this heater was reported to be in good condition. One is not surprised, however, to read elsewhere that considerable trouble from plugging was encountered in some early heaters, since the tube temperature would often be below the dew point of the gas.

This installation of 1881 was the result of an invention of Obadiah Marland covered by U. S. Letters Patent No. 205282 dated June 25, 1878, describing a plate type air preheater for use in combination with forced and induced-draft devices. In return for several mill owners' investment toward building and testing the apparatus they were to receive exclusive and free license to its use. However, when the apparatus was constructed in 1881 it was built of tubes instead of flat plates as described by Marland.

A plate-type air heater was patented in 1888 which was quite similar in some details to some which have been designed in more recent years. A paragraph from the U. S. Patent Specification[2] reads: "The object of the invention is so to utilize the products of combustion that the waste gases will escape from the smoke pipe practically deprived of caloric, and to heat the air fed to the furnace to such an extent that a ready combustion of fuel is effected." Fig. 1 is a reproduction from the patent showing a heater designed to be supported from the deck beams of a ship. The bottom plate in one view is shown divided and hinged so that ashes, soot, etc., will drop out when the bottom plate is removed.

The plate-type air heater was first used successfully in land practice in England. The reason for its application may be attributed to economic developments of the coal industry in England about the beginning of the present century. The increased demand which was created about that time for sized washed nut coal suitable for burning on mechanical stokers resulted in the increased production of coal of this type and the consequent accumulation of immense quantities of small screenings. For these there was no demand, although the heat value was around 8500 B.t.u. per pound, and consequently the market price became very low. Even so, it was not found economical to transport this fuel any distance from the mines because it could be burned only at such low combustion rates and with such low efficiency that the freight charge per unit of heat actually utilized was great enough to prohibit its use at this time except at plants in close proximity to the mines.

Water economizers were to some extent already in use at this time but presented no great field for improvement in thermal efficiency of the boiler plants for the reason that the steam pressure used in many boiler plants was less than 125 lb. per sq. in. and the amount of heat which could be recovered by a water economizer was therefore small. Realizing that considerably more heat could be recovered by using air, because of the much higher temperature differential available with this medium, some water economizers were actually converted to air preheaters by simply substituting air for water as the cooling medium. This was not very satisfactory since the rate of heat transfer was low and the power con-

[1] "Warm Blast Steam Boiler Furnace," by J. C. Hoadley, 1886.
[2] U. S. Letters Patent No. 386,527, July 24, 1888.

sumption to overcome the air resistance was very high. Moreover, tubular air heaters of other designs had been used in marine practice for some years with no outstanding success. So it was thought advisable and necessary, by those industrially minded scientists and engineers interested in burning this cheap waste fuel smokelessly at higher combustion rates and with higher efficiency, to invent and develop an improved type of air preheater.

Early Development of the Plate-Type Heater in England

In response to this need in England for a better air preheater the plate-type heater was produced. And perhaps the most popular design and one of the first to be used successfully was that designed and patented by W. R. Wood in 1907. A photographic reproduction of one element of the first heater of this type is shown in Fig. 2. It was installed in Glasgow, Scotland, at the Cassel Cyanide Works about 1908 and used in conjunction with an underfeed stoker burning cheap small coal.

The term "element" has become the generally accepted name applied to the envelope or flat conduit through which the air passes. Several of these elements, separated in parallel relation by spaces through which the heating gas passes, constitute the air heater assembly. The first air heater elements were built up of four pieces of sheet steel cut, shaped and riveted to steel bar spacers. Adjacent elements were fastened together and sealed at the air inlet and outlet openings by means of bolts through the holes shown in the edges of the element walls. The element assembly was placed in a horizontal position in the boiler flue and air was induced through the heater by a forced-draft fan having its inlet connected to the air heater outlet.

The length of the elements in the direction of gas flow was only eight feet and the width, or radius of the outside of the semi-circular air flow path, was about four feet. The plates were spaced one inch apart in constructing the elements, and these were spaced about one inch apart in their assembly. Thus the entire quantity of gas and air was divided into thin parallel layers in passing through the heater. The elements were made semi-circular in shape in order to reduce the power required to force the air through the heater.

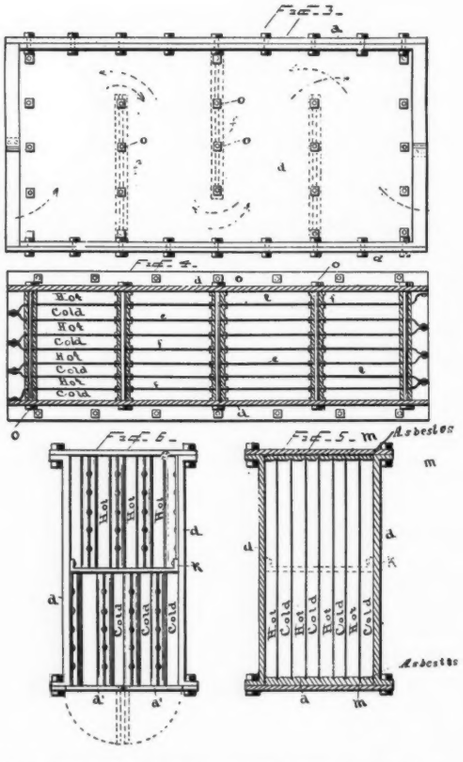


Fig. 1—U. S. Patent drawing of early plate-type air preheater

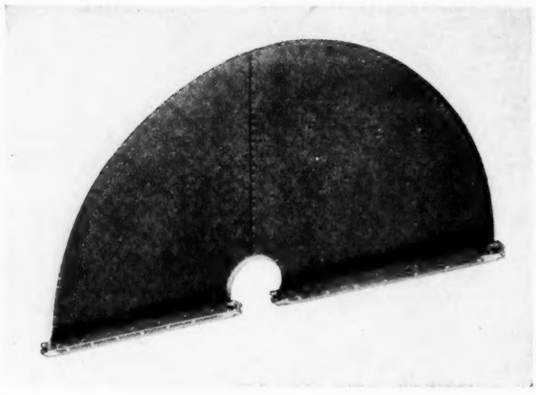


Fig. 2—One element of first plate-type air preheater installed in Great Britain

Different as this heater of a quarter century ago was, in details of construction and application, when compared with a modern plate type heater, nevertheless, it gave satisfactory results due to the proper application of the knowledge that, since air must be heated by convection, intimate contact of air and gas with the separating heat transfer medium must be obtained. Dividing both the air and gas into thin alternate layers separated by a thin steel plate insures this intimate contact, turbulence and high convection heat transfer rates.

By the efficient recovery of heat from the waste gases, the overall boiler room efficiency was increased; the use of preheated air improved combustion conditions in the furnace; higher combustion rates could be maintained even with the cheap waste coal with the result that the plant capacity was considerably increased.

Introduction of the Plate-Type Heater into the United States

In 1920 a plate-type air heater was used at Chester, Pa., in an experimental laboratory erected for the Emergency Fleet Corporation for the purpose of testing a Scotch marine boiler fired with oil, pulverized coal and hand-fired coal. The tests were made by the United States Shipping Board in cooperation with the Bureau of Mines. The heater used in this experimental installation had 34 elements, each 5 ft. $3^3/_4$ in. long by 4 ft. 3 in. high and $1^5/_{32}$ in. thick across the air space between the plates. The elements were assembled in a vertical position with 1 in. gas spaces between them.[3]

It was not, however, until 1922 that the first commercial order for a plate-type air preheater was placed by the Kansas City Power and Light Company. This heater had 88 elements 12 ft. 6 in. long by 5 ft. 3 in. wide with a 1-in. space between plates for air passage. The elements were assembled in a vertical position with $1^1/_4$-in. gas space between. The construction of one of the elements of this heater is shown by Fig. 3. It will be noticed that in some details the design was similar to the first English plate-type element used over fifteen years before. The air envelopes were of riveted construction, the edges of the plates being fastened together in this manner with a 1-in. thick bar between the plates, thus providing a 1-in. air space. The method of fastening the edges of adjacent elements together at the air inlet and outlet openings and of sealing these joints was by the use of U-shaped clips bolted over the two edges, in place of the bolts alone, as used in the early English design. The element plates were of steel and were cut with square corners, but since both the air inlet and outlet openings were in the same edge of the element the air took a C-shaped flow path of variable length in passing through the heater, somewhat similar to the English

[3] Bureau of Mines Bulletin 214.

design. The elements were assembled in a vertical position in a steel casing with $1^1/_4$-in. spaces for gas passage between adjacent elements. The air side spacing between the plates was maintained by the use of pipe and bar spacers and the gas side spacing between adjacent elements was maintained by the use of small buttons welded on the casing thus providing a spacing notch for each element.

At that time the standards followed in making apparatus of this kind were low compared with the demands of the present day, but the design described above was entirely satisfactory and compared favorably with power plant practice of the time. And incidentally this heater is still in daily operation after having served practically continuously since it was installed on a stoker-fired boiler unit burning high sulphur Kansas and Missouri coals.

The reason for this first power plant plate heater application in this country was the desire to burn low-grade Middle Western coal at higher combustion rates, with higher efficiency, more satisfactory furnace conditions and, in consequence, to obtain greater steam output from existing boiler units. These results were obtained and are now accepted as proved advantages of the use of preheated air as applied to stoker-fired plants.

Other early users of the plate-type air heater in this country were the Duquesne Light Company of Pittsburgh and the Commonwealth Edison Company of Chicago.

Reasons for the Sudden Popularity of Air Preheaters

It appears, therefore, that in both Great Britain and America, plate-type air heaters were first applied to stoker-fired boiler units to enable poor grades of coal to be burned at higher combustion rates with the object of increasing steam output and decreasing cost. That satisfactory results were obtained and these objectives reached was not, however, the reason for the great popularity that was soon to be accorded the plate-type heater and air heaters in general. The use of preheated air on the early stoker units to which it was applied did improve combustion conditions, overall efficiency and plant capacity but it also increased both furnace and stoker maintenance, due to higher furnace temperatures and the effect of preheated air on the stoker parts. There were therefore two limits immediately imposed which had to be considered in applying air preheaters to existing units, and these undoubtedly retarded air preheater development in Great Britain up until the time that the plate-type air heater was first used in the United States.

At about this time, however, two incidents in the history of steam-power generation occurred, namely, the successful application of the water-cooled furnace and pulverized fuel firing. Without these two developments, together with one other mentioned later, the use of the enormous amount of air-preheater surface which has been installed during the past decade would have been neither possible nor necessary. Conversely, the use of air preheaters has greatly enlarged the field of application of both water-cooled furnaces and pulverized fuel firing—in the former case because preheated air partly counteracts the great reduction in furnace temperatures caused by water cooling, and in the latter case because it aids in obtaining and maintaining proper ignition of pulverized fuel, thus making it easier to burn low volatile coal in pulverized form. Air preheaters have also extended the field of application of pulverized coal by providing a satisfactory drying medium by means of which wet coal may be sufficiently dried during the process of pulverization to enable it to be more easily and satisfactorily handled by the transporting, feeding and burning equipment.

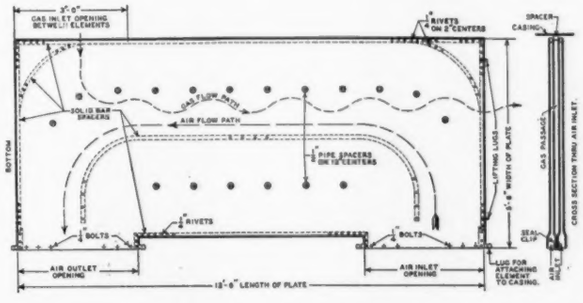


Fig. 3—Element of first commercial plate-type air preheater installed in the United States by Kansas City Power and Light Co. in 1922

In 1922, during which year the first commercial plate-type air heater contract was closed in this country, it so happens that the first contracts for equipment employing steam pressures higher than 400 lb. were also closed. With higher steam pressures the minimum final gas temperature obtainable with boiler alone was correspondingly increased and the maximum obtainable boiler efficiency was at the same time decreased. Auxiliary heat recovery equipment, additional to boiler and superheater, was therefore necessary in order to equal or improve the boiler room efficiencies that were possible with lower pressure steam. The water economizer and the air preheater are used for this purpose. However, the advantages of multiple-stage bleeding for feedwater heating have popularized this system to such an extent that water economizers alone fail, in many cases, to produce the desired heat recovery between boiler and stack, and air preheaters must be used. Since the air preheater by itself will generally give the desired heat recovery at lower cost than the combination, an air heater alone is often used when there is no objection to the higher preheated air temperature which results.

Thus we see that the reasons which promoted the early application of air preheaters have not in themselves been responsible for their widespread use and their present position in the modern boiler room.

Difficulties Experienced with Plate-Type Heaters

The minor troubles encountered during the first few years after the introduction of the plate-type heater may be classed as structural. An appreciation of the value of close shop inspection and the use of tolerances and tolerance gages, together with some changes in details of construction, has gone far toward the complete elimination of structural troubles in most makes of plate-type heaters.

Among the early structural ailments a few will be mentioned here. It was stated previously that the heater sold in 1922 had riveted elements, but despite the fact that these rivets were spaced only two inches apart (see Fig. 3) the plates bulged slightly between the rivets with the result that there was considerable air leakage into the gas stream. The U-shaped clips used to seal the joints between adjacent elements at the air inlet and outlet openings were a source of trouble and leakage. Also, the practice of fastening each element rigidly to the casing, with an asbestos seal strip in the joint so made, did not insure a reliable seal against leakage nor satisfactory provision for expansion especially in the longer heaters which soon came into use. Still another change was found necessary in the method of maintaining the proper plate spacing throughout the heater. It was found that the use of only a few scattered pipe-spacers or angle-clips, while fairly satisfactory if accurately located so as to be in perfect alignment throughout the heater, did not provide sufficient rigidity in the elements to prevent damage from rough handling during shipment or erection of the elements.

The more serious failings in the design and application of plate-type air preheaters during the first few years after their introduction in this country were due in part to the absence of any available experimental data on heat transfer and draft loss in apparatus of this kind, and in part to a lack of appreciation of the importance of good air and gas distribution and its effect on both performance and maintenance of the apparatus. Many of the early installations were made to improve existing

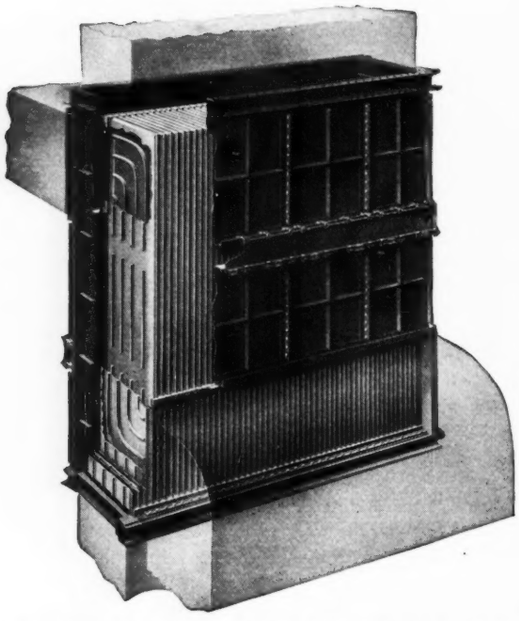


Fig. 4—Assembled view of C-E plate-type air preheater

boiler units and in many such instances space limitations resulted in air preheater applications which violated many of what are now considered the fundamental principles of good duct and air-heater design and arrangement.

Published scientific data on heat transfer which were available at the time of the introduction of the plate heater into the United States, pertained almost entirely to heat transfer to the surface of circular tubes. So many variables are involved in such heat transfer equations such as velocity, density, temperature, viscosity, nature of fluid, nature of surface, dimensions of tubes, etc., that it was particularly difficult to evaluate such data and apply them to a plate-type heater operating with two gaseous fluids having variable temperature and velocity, in apparatus not containing tubes but made up of flat plates spaced variable distances apart.

The data on heat transfer with various diameter tubes indicated that a higher coefficient could be expected with closer plate spacings, but before this could be satisfactorily demonstrated or disproved the economics of the application of air heaters had been quite thoroughly investigated and there was large demand for air heaters of enormous heat recovery capacity, especially in connection with pulverized fuel firing. It became at once necessary, in order to meet these requirements, to produce better performance from heaters occupying less space and selling for less money and this led to the use of closer plate spacing. Many heaters were installed with $^1/_2$-in. air and $^1/_2$-in. gas spacing before it was discovered that the increase in transfer rate due to decreasing the plate spacing had been over-estimated, while the corresponding increase in draft loss had been under-estimated.

Two other difficulties which a few users have had with plate-type air heaters are just as common in tubular and some regenerative type heaters, namely, corrosion and plugging. These two ailments generally travel hand in hand and are caused one by the other. In some installations poor gas distribution to the heater will cause soot and ash to settle on the surface in a region of low velocity. This deposit in turn increases the temperature gradient between gas and plate and the low plate temperature starts corrosion. In other installations where an attempt to recover a maximum amount of heat in the air heater has been resorted to, the final gas temperature and initial air temperature may be so low as to produce a plate temperature below the dew point of condensables in the products of combustion. The resulting deposition of the liquid phase on the plates may then cause soot and dust to collect and thus bring about plugging.

Changes in Plate-Type Heater Construction Since 1922

In the preceding section some of the shortcomings of the first air heaters have been enumerated. The same year in which the Kansas City air heater was sold, its exponent changed from the riveted element construction shown in Fig. 3 to a welded construction which not only eliminated the possibility of leakage but made possible the proper shaping of the plates at the edges to give more nearly stream line flow of the gases entering and leaving. The following year this manufacturer eliminated the leaky U-shaped clips, used to seal the joints between adjacent elements at the air openings, and resorted to field welding of these joints. The same year also continuous bar and angle spacers were adopted to maintain the distances between the plates, to provide also for better distribution of air and gas over the entire heating surface, and to make the elements stronger and more rigid. Then followed the elimination of the practice of bolting the elements rigidly to the casing with the asbestos seal strip between. In place of this, continuous flexible-steel seal plates are now used which are welded to the elements and to the casing in such a manner that the elements are free to expand with respect to the casing. This freedom is important in long heaters since there may be several hundred degrees difference in the average temperature of the elements and casing.

The next improvement made by this manufacturer was the provision of means for inspecting and lancing the gas passages at short intervals without interruption of service. Narrow doors were designed to extend completely across the elements at one, two or three elevations depending on the height of the heater. Every individual gas passage can by this means be inspected at several points throughout its length and by using an air or steam lance the entire surface may be cleaned at desired intervals of time. Figs. 4 and 5 illustrate the result of these improvements by this one manufacturer who now puts out a completely welded heater, continuous air and gas side spacers, flexible-steel seal and expansion strips welded between element assembly and casing, and narrow inspection or lancing doors.

Other manufacturers have developed plate-type heaters along somewhat different lines either due to their own and others' patent restrictions or because they consider certain features of their respective products superior to others. For instance, one company has for many years built a heater which is not an assembly of manufactured "elements" or groups of elements but is rather an assembly of plates upon which no work of fabrication has been done except cutting to the proper size. The plates are flat and there are no attachments in the form of spacers or guide angles; they could be shipped direct from the plate mill to the job and there assembled into the

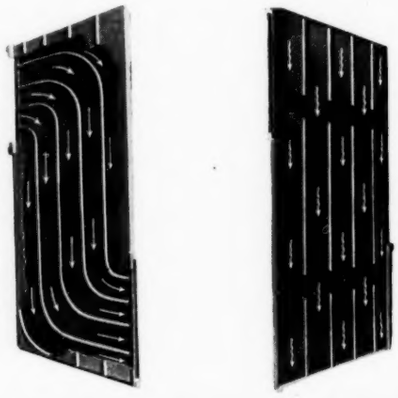


Fig. 5—(Left) gas side and (right) air side of elements of preheater shown in Fig. 4

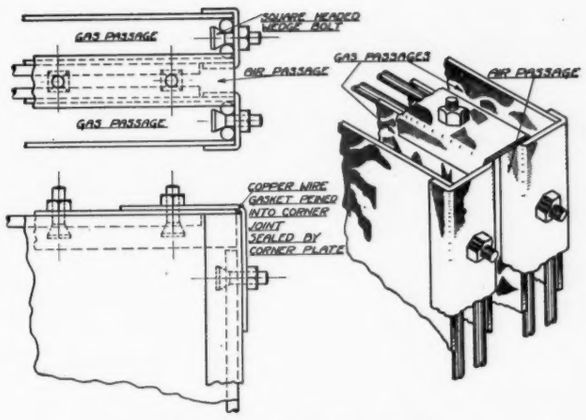


Fig. 6—Details of Thermix air preheater

heater. Up until a few years ago this heater was assembled by compressing the plates against specially designed gas and air passage spacers located alternately with the plates. These spacers were solid except at the fluid inlet and outlet openings where spiral spring-type spacers were used. Compressing the plates against the spacers was accomplished by numerous threaded rods extending entirely across the heater with nuts on the threaded ends with which to compress the plates and spacers between the end plugs. Recently the methods of assembling the plates in this heater were improved upon. The new system used by this manufacturer still employs simple flat plates which are fastened together at the edges by placing two small rods of proper diameter between the plates near the edge, placing a small channel over these bars and plate edges, then passing small bolts with wedge-shaped head between the rods and through the web of the channel in such a way that, by tightening nuts on the outside, the plates are pressed apart against the flanges of the channel thus forming a tight joint. Fig. 6 illustrates this novel feature of this heater. Guide angles in the gas and air passages are not provided. So here we have a manufacturer who has developed his heater without the use of shop-fabricated elements or heating surface units so that the purchaser may order replacement surface direct from the plate mills and rebuild his own heaters.

Another manufacturer uses welded elements, individually assembled in the casing but not welded together at the air inlet and outlet of the assembly. Instead, these openings in each element are provided with frames which are machined so as to make a tight joint with frames of adjacent elements when placed side by side and rigidly bolted to the casing. This manufacturer considers it a most valuable feature of his design that the elements can be removed, turned end for end, and replaced, thus doubling the life of the surface.

Still another manufacturer, offers a heater of sectional design. This heater is made up of one or more cross-flow sections in series or in parallel with other similar sections. In this type of heater the gas flows upward or downward through the sections and the air flows at right angles to the gas in each individual section, but in a counterflow direction through each series group as illustrated by Fig. 7. The air and gas passages are formed of flat plates welded on all four edges but with the four corners notched out. Numerous holes in every plate permit the use of tie rods which pass through to the outside of the casing. Pipe spacers on these rods, and gas and air guides between the plates, permit the nuts on the ends of the rods to be drawn up tight to seal the many holes against leakage and at the same time to produce a rigid heater section. Sealing between gas and air passages at the notched corners is accomplished by forcing an asbestos fiber strip against the plate edges, the seal strip being backed up by an angle to which pressure can be applied. Permanent soot blowers are recommended for cleaning. This is necessary because this type of heater cannot be readily inspected or cleaned. The gas passages of all sections except the extreme upper and lower ones are inaccessible and these end sections can be inspected or cleaned only from the inside of the gas duct. The initial installation of permanent soot blowers between sections, or provision for their future addition if found necessary, is therefore important in this type of heater.

Limitations of the Plate-Type Heater

The plate-type air heater, the structural developments and principal styles of which have been discussed, may be used for any purpose for which an indirect fired air heater is desired. There are few practical limitations in size except those imposed by the plate mills, which in turn may be overcome by welding two or more plates together. However, the use of single heater elements longer than 25 ft. will seldom be found necessary and this length may be purchased from stock in widths up to 5 ft. In the matter of assembled width of heater the only possible limitation may be caused by the method of support. The widest boiler in the world which has a furnace width of 55 ft. is being equipped with plate-type air preheater surface weighing nearly 200 tons, including the casing.

High-temperature limitations may be overcome within limits by the proper selection of metal for the plates and proper application of principles of air-heater design. The air heaters used in steam boiler plants are generally built of ordinary hot-rolled or copper bearing steel sheets of 12-gage thickness. Since they are generally of the counter-flow type it is not considered good practice to use entering gas temperatures higher than 850 to 900 fahr. A similar design of heater using the parallel-flow principle, or one employing the counter-flow principle with extremely cold air or a much larger quantity of air than gas, could be used with somewhat higher entering gas temperature. Even the variation of fluid velocities affects the maximum gas temperature which may be used since the plate temperature will generally be closer to the temperature of the fluid having the higher velocity. For higher temperature than can be used with ordinary steel, cast iron and special alloy steels have been used. Several grades of alloy suitable for the temperature range between 1000 and 2200 fahr. are available in this country, but the high cost of this material prohibits

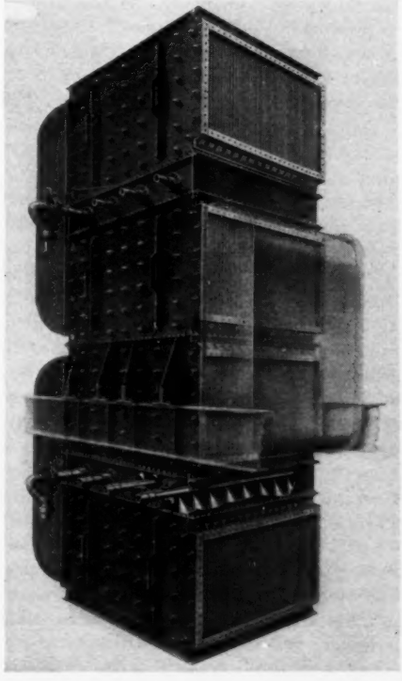


Fig. 7—Assembled view of Foster Wheeler plate-type air preheater

its use in many cases where a high temperature plate-type heater would be otherwise justified.

Low temperature limitations also may be overcome by proper selection of metal and proper design. In power plant practice there is a minimum plate temperature limitation which is imposed by the fact that the flue gases contain condensables that deposit on the plate in the liquid phase if the plate temperature falls below the dew-point. In the early days of air heaters it was thought that the flue gases contained only stable gases and inert solids such as carbon dioxide, sulphur dioxide, nitrogen, water vapor and ash. Consequently dew-point calculations were made for the water vapor only. With the average fuel if the water vapor were the only condensable in the flue gases, the plate temperature could be reduced to a safe minimum of 150 fahr. But it is now appreciated that sulphur trioxide may be formed which, in the presence of the water vapor always present, may form sulphuric acid. The dew-point of gases containing this acid is much higher than if water alone were present. It is known also that the sulphur content of the fuel, composition of the ash and method of firing all have a bearing on the dew-point of the gases but knowledge of these variables does not make it possible at the present time to predict accurately the minimum safe plate temperature for the air heater. Where slight corrosion is encountered or anticipated, this condition may be corrected or prevented by various modifications in the standard arrangement such as by-passing air or gas, recirculating air or gas, using variable amounts of heating surface, etc. Where gases of very high dew-point must be handled acid resisting metal is used.

Uses of the Plate-Type Air Heater

Plate-type air preheaters have been applied to steam boilers in the power plants of practically every industry in which the cost of steam or power to operate machinery is an appreciable item compared to the total cost of the finished product. In such industries the economic use of the fuel burned in the process of the generation of the required steam or electric power, or in the production of process steam, is of such importance as to justify the use of air preheaters. Examples of these are the public utilities, iron and steel, paper and motor car industries.

In many other industries fuel is burned for the purpose of evolving heat which is used directly in the process of manufacture of a product. Such industries, in the interest of recovering the sensible heat in the waste gases, have found considerable use for waste-heat recovery apparatus either in the form of waste-heat boilers or air preheaters. Examples are found in oil refining, the ceramic industry and in many departments of the iron, steel and metal products industries.

In still other industries, where heat is required for drying or otherwise processing the product of manufacture, it is necessary and imperative that this heat be supplied in the form of clean dry preheated air. Plate-type air heaters have been used for this purpose to some extent in such industries as food, ceramics and glass manufacture. However, in most food products plants and in those turning out lacquered, enamelled or painted ware the air must be supplied by means of direct fired air heaters which are generally used in conjunction with intricate and extensive conveying and temperature control apparatus, into which field the manufacturers of the power-plant type of air heaters have not gone extensively.

From the records of the leading manufacturer of the plate-type air heater, initially designed for steam power plant use, we find that nearly 6,000,000 sq. ft. of heating surface has been installed in the U. S. alone, distributed among the industries in order of heating surface area as follows: public utilities, mining and metallurgy, automobiles, pulp and paper, oil refining, building materials, textiles and rayons, warehouse, chemicals, food, rubber, schools and institutions and ceramics.

For much of the material regarding the early development of the plate-type preheater in England the author is indebted to Mr. B. Wyatt Bagshawe, M. I. of Mech. Eng. of London.

System of Coal Classifications Culminates Six-Year Research

Six years of data collecting and research by the Technical Committees of the Sectional Committee on Classification of Coals, which is sponsored by the American Society for Testing Materials and functions under the procedure of the American Standards Association, culminated in the formulation of a tentative system for the classification of coals, according to the various ranks, ranging from lignite to anthracite, and also a system for classification according to quality and grade. Reports of this work were presented at a meeting of the committee held at the Experiment Station of the U.S. Bureau of Mines, Pittsburgh, Pa., on October 26.

The Subcommittee on Boundary Lines for Coal Classification presented a report in which coals were subdivided. The ranks of coal are classified into four groups, namely, anthracite, bituminous, sub-bituminous and lignite. The anthracite group consists of graphitic anthracite, normal anthracite and semi-anthracite. The bituminous group consists of low volatile bituminite, medium volatile bituminite, high volatile bituminite A, high volatile bituminite B and high volatile bituminite C. The sub-bituminous group consists of sub-bituminite A, sub-bituminite B and sub-bituminite C. The lignitic group consists of lignite and brown coal.

The boundary lines between the different classes of anthracite and between the low moisture bituminous coals are defined by the percentage of fixed carbon on a dry mineral matter free basis. The boundary lines between the classes of high moisture bituminous coal and sub-bituminous coal and lignite are defined by the B.t.u. value on a moist mineral matter free basis; moist meaning that the coal contains the normal bed-moisture but not any extraneous or surface moisture.

The names given to the different classes of coals were recommended by the Committee or Nomenclature.

To Stimulate Interest of Younger Members

For the purpose of sustaining and stimulating interest among the younger members of the A.S.M.E. Metropolitan Section (New York) a Junior Group has been formed which will hold fortnightly meetings of a semi-technical nature and arrange for occasional inspection trips. This plan, it is hoped, will enable the younger members to become better acquainted and result in their taking a more active part in the activities of the Section.

Central Station Output Fails to Hold Gain

Production of electricity by central stations as compiled by the Edison Electric Institute, shows a decline in output throughout October, as compared with September. The output while above that of 1932 represented a smaller percentage gain than either August or September of this year. The gain for October 1933 averaged 7.1 per cent, compared with October 1932, whereas that for September averaged 11.1 and August 14.4.

Steel and Tubes, Inc., Cleveland, Ohio, announces the following recent changes in personnel: A. V. Grove has been transferred from the Cleveland office to the Chicago office in the Sales Department. R. E. Doyle is now sales correspondent in the Cleveland office. J. F. Keeler is now sales engineer with headquarters at the Cleveland office.

High-Temperature Steam Experience at Detroit

By P. W. THOMPSON

Chief Engineer of Power Plants, The Detroit Edison Company

and

By R. M. VAN DUZER, Jr.

Engineer, Production Department, The Detroit Edison Company

This paper* is concerned with presenting the experience of The Detroit Edison Company, to date, with the various materials used in the construction of a 1100 fahr. superheater and piping system in operation over 23,000 hr., 21,169 of which were between 1000 and 1100 fahr., and a 10,000-kw., 1000 fahr. turbine installation in operation for 11,231 hr., 7,832 of which were at 1000 fahr. A description of both installations, the reasons for the choice of materials used, and an account of the operating experience are described. Information regarding the thermal performance of the turbine is being presented in an accompanying A.S.M.E. paper by W. A. Carter and Prof. F. O. Ellenwood.

EXPERIENCE gained from equipment using steam as high as 1100 fahr. in one of the power plants of The Detroit Edison Company, since the fore part of 1929, leads the authors to believe that the design of steam-generating plants using temperatures in the neighborhood of 1000 fahr. is entirely feasible provided users are prepared to specify the high-priced materials that experience so far dictates. A small oil-fired superheater, delivering 1100 fahr. steam to a piping system has been in operation at the Trenton Channel plant since March 1929. The information obtained in the operation of this equipment served as a basis of design for the separately fired superheater, piping and 10,000-kw. turbine-generator which was placed in operation with 1000 fahr. steam the latter part of 1931 at Delray Power House No. 3.

The principal trouble with the two installations has been encountered at Trenton Channel and has been caused by the leakage at flanged pipe joints. The use of better bolting material and changes in flange design have materially improved conditions. Replacement of a cracked desuperheater casting was necessary in the Trenton Channel set-up and a new turbine throttle valve of improved design has been purchased to correct recurring leakage at the bonnet flange at Delray. With these exceptions no troubles of a serious nature have been experienced.

Examinations of the austenitic 18 per cent chrome, 8 per cent nickel alloy which was used in the construction of the Trenton Channel superheater and piping system, show that this material has deteriorated in service due, probably, to precipitation of chromium carbides along the grain boundaries. There is, however, no evidence thus far of inter-crystalline corrosion and no such serious reduction in physical properties as would lead to rejection of this material for steam service in the 1000 to 1100 fahr. range. Tests of other steels belonging to the low alloy class have disclosed no marked change in their properties. Since the time these two experiments were undertaken there has become available much more information concerning the behavior of alloy steels and this, together with advances in the art of manufacture, has made the selection of stable alloys for this class of equipment a simple matter for the designer.

Operation with high-temperature steam has presented no problems of an unusual nature. The equipment, particularly the turbine, has been given close attention because of its experimental nature. The turbine at the present time, however, is receiving only the same care as other equipment in the Delray Power House.

This paper is primarily concerned with a discussion of the reasons for the selection of the materials that were used, results of metallurgical examination, operating features, and troubles that have been experienced and remedies applied. More detailed descriptions of the installations and design assumptions have already appeared in magazine articles (*1*), (*2*), (*3*), (*4*), (*5*), (*6*).[1] Information regarding the thermal performance of the turbine is being presented in an accompanying A.S.M.E. paper (*7*).

Purpose of Experiment

The choice of the unusually high temperatures for these experiments was made in order to determine what effects would be produced on alloys then available for power plant equipment. The experiments were undertaken as steps designed to eliminate one of the factors now limiting increase in efficiency of the simple regenerative turbine cycle by allowing initial pressures, higher than those now in use (1).

It was decided to divide the experiment into two parts at the time a decision was made in 1927 to proceed with the design and installation of a 1000 fahr. turbine. The first part consisted of a separately-fired superheater and piping system

* Contributed by the A.S.M.E. Steam Power Division for presentation at the Annual Meeting, New York, N. Y., Dec. 4 to 8, 1933, of the American Society of Mechanical Engineers.

[1] Numbers in parentheses refer to similar numbered items in the Bibliography given at the end of the paper.

designed to operate with 1000 fahr. and later with 1100 fahr. steam to give preliminary data regarding the effect of the high superheat on tubes, piping, pipe fittings, and particularly, pipe joints, while the second step consisted of the installation of a 10,000-kw. turbine-generator together with piping and superheating equipment designed for operation with 1000 fahr. steam.

Information gained from the first installation at Trenton Channel proved invaluable in the design and selection of materials especially for the piping system of the Delray apparatus.

No provisions were made in either group to utilize steam at a pressure higher than 400 lb. It was believed that the high temperature without adding the possible complication of high pressure would provide the information most desired. Consequently, in both experiments, steam at station pressure was utilized.

Description of Equipment

The Trenton Channel equipment consists of an oil-fired superheater supplied with 400 lb., 700 fahr. steam from the station header. Approximately 65 ft. of $5^1/_2$-in. O.D. tubing conducts the high-temperature steam to a desuperheater where the temperature is reduced before passing to one of the house-service turbines. The superheater, supplied by The Babcock & Wilcox Company is of the radiant type, containing 153 sq. ft. of refractory covered heating surface, and is capable of adding 400 deg. of superheat to 6000 lb. of steam per hour from an initial temperature of 700 fahr. The tubes which comprise the rear and side walls of the unit are covered with refractory blocks cemented to welded-on-lugs on the tubes to prevent direct exposure to the radiant heat.

The high-temperature piping system contained a valve, eight flanged pipe joints and a desuperheater. The pipe ends were provided with Van Stone, Sarlun laps, the faces of which were provided with a serrated finish for obtaining experience with gasketed as well as seal-welded joints. All joints in the piping system as well as the superheater inlet and outlet joints were constructed to the 600-lb. A.S.A. flange standard. The original line has been somewhat changed by the addition of experimental joints of heavier construction.

The Delray installation consists of an oil-fired superheater, interconnecting high-temperature piping, a 10,000-kw. British Thomson-Houston turbine-generator, condensing equipment,

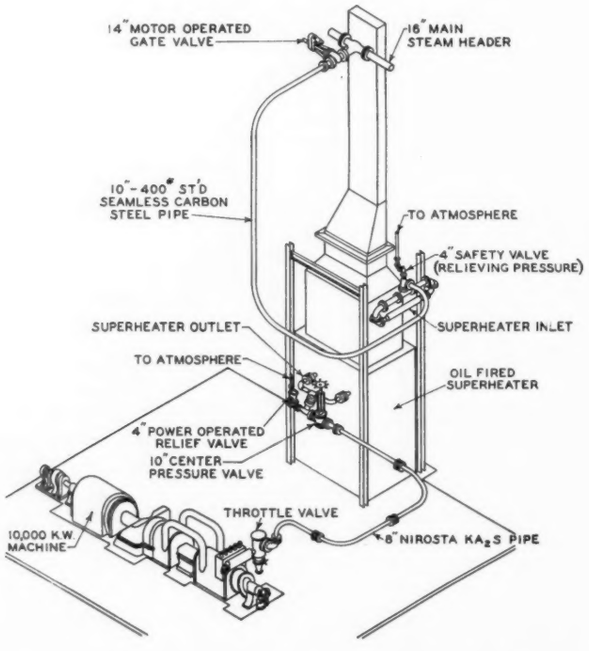


Fig. 1—Isometric view of high temperature installation

and auxiliary pumps and heaters, together with the piping necessary to connect the turbine flow circuit into the existing plant systems (5), (6). An isometric view of the installation is shown in Fig. 1. The equipment occupies a space provided for a future boiler and is compactly arranged.

The superheater contains 3957 sq. ft. of surface arranged in three sections; a top convection section, a middle semi-convection-radiant portion, and a lower radiant section which encloses the combustion chamber on the two sides and bottom. The tubes in the lower section were provided with the same type of refractory covering as used in the Trenton Channel superheater. The unit was designed to superheat 90,000 lb. of steam per hour from 700 to 1100 fahr. at a pressure of 455 lb. per sq. in., although the ordinary operating pressure does not exceed 400 lb.

The interconnecting pipe line (2), consists of the superheater outlet fittings, a 10-in. center-pressure type stop valve, two reducing fittings, and 43 ft. of $8^1/_2$-in. O.D., $^5/_8$-in. wall tubing. A power-operated safety valve was also added at the outlet. Several different types of joint construction are used in the twelve joints which are in the line. Five of these joints are made with full strength butt welds and reinforced with bolted flanges; the remaining seven are bolted joints. The throttle valve joint is a modified tongue and groove, 1500-lb. A.S.A. standard. The joint between the reducing ell and the tubing, as well as the tubing-reducer joint near the superheater, are raised face 1500-lb. standard. The joints on either side of the valve are made up with hairpin spring washers to provide flexibility inasmuch as the valve flanges are made to the 600-lb. standard. The sixth and seventh bolted joints are at the small tee where the safety valve is located, and are both 900-lb. standard.

The turbine is a two-cylinder, single-shaft, 3600-r.p.m., straight-impulse type unit containing nine stages in the high-pressure cylinder and eleven stages in the low-pressure portion. It was designed for steam at 365 lb. per sq. in. gage, 1000 fahr., exhausting to 1 in. Hg absolute. Steam is extracted at the ninth, fourteenth, and seventeenth stages for feedwater heating. Except for the double-casing construction, and the external supply of saturated steam which is supplied to the high-pressure shaft packing to cool the shaft and bearing, the general design of the turbine differs little from impulse turbines manufactured in this country. A cross-section of the turbine unit is shown in Fig. 2. The generator, rated at 10,000 kw. at 0.8 power factor and 4800 volts and equipped with two direct-connected exciters and a closed ventilation system, is of standard design. The condensing equipment and auxiliaries are identical with those used for the 4000-kw. d.c. auxiliary turbine-generators in the power house.

Material Selections

At the time the Trenton Channel equipment was being designed in 1927, the austenitic 18 per cent chrome, 8 per cent nickel alloy was being offered as the ideal material for equipment operating at elevated temperatures. Various investigators in this country and abroad had established its high physical properties and resistance to creep at temperatures in the range from 1000 to 1100 fahr. The principal objections to its use were the high cost and difficulties of fabricating in either the cast or wrought form.

Inasmuch as this alloy possessed such desirable properties and was recommended by the builder of the superheater, this type of alloy was selected for part of the radiant section, the piping, and the valve and fittings used in the pipe system. The superheater was fabricated with low-carbon steel tubing in the section where the steam temperature does not exceed 800 fahr. while the remainder contained the so-called 18–8 tubing then known as Enduro S188 and now designated as Nirosta KA2. The typical analysis of this steel as given by the maker was C. 0.16 (maximum), Cr 17–20, Ni 7–10, and Si 0.50 (minimum), all in per cent by weight. Subsequent

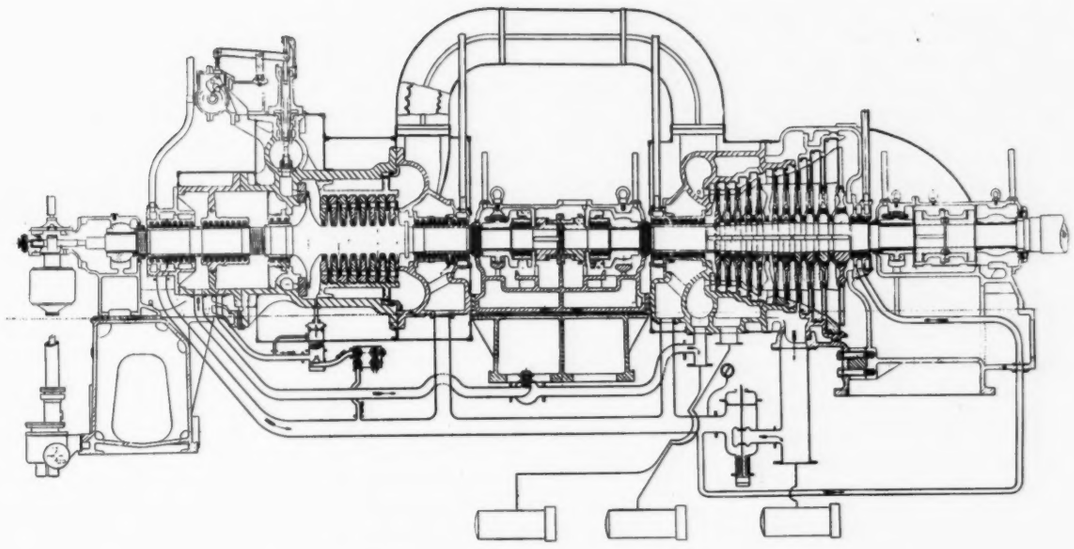


Fig. 2—Cross-section through 10,000-kw. 1000-deg. turbine at Delray

analysis of a removed tube showed a carbon content of 0.05 per cent, which places this material in the low-carbon or KA2S class.

This same material was selected for the high-temperature piping system because of its desirable properties and the fact that it could be obtained in a 5-in. pipe size. This $5^1/_2$-in. O.D., $^3/_8$-in. wall tubing was made by The Babcock & Wilcox Company to the same analysis as given above. Later determinations show a carbon variation from 0.06 to 0.09 per cent. The loose companion flanges, valve and desuperheater castings were made from Rezistal 2C, a material similar to KA2 but having a maximum carbon content of 0.25 per cent and a silicon addition of 2.0 to 2.5 per cent. These parts were supplied by the Chapman Valve and Manufacturing Company. The bolted joints were made up with Seminole Hard, a chrome-tungsten-vanadium steel, heat-treated to give a yield point in the neighborhood of 200,000 lb. per sq. in. This alloy was selected as the result of creep tests conducted at the University of Michigan on a similar steel. The typical composition of this steel is given in Table I. It possesses a resistance to creep of about 7000 lb. per sq. in. at 1000 fahr., based on an extension of one per cent per 100,000 hr., and is fairly stable at the operating temperature. Various other bolting steels have not proved as satisfactory. Numerous gasket materials have been used, the most successful being plain $^1/_{32}$-in. sheet monel.

After the Trenton Channel equipment had been placed in service and before final decisions had been made regarding the materials for the Delray superheater and piping, reports were received from various sources, including steel makers in England and users in the oil industry, of failures that had been experienced with the 18–8 alloy. These failures had occurred in parts subjected to corrosive mediums and were due to intercrystalline corrosion which was believed to have been the result of precipitation of chromium carbides at the grain boundaries.

In view of these unfavorable reports, the performance of this material was carefully studied. A piece of the tubing from the Trenton Channel pipe line was removed and examined. Changes, to the extent predicted, were not found, as only slight carbide segregation and a 5 per cent loss in impact value at room temperature was in evidence. The physical properties after this period of service were so good that this alloy was used for the hotter sections of the Delray superheater and the piping between the superheater and the turbine. Care was taken to specify, where possible, the low-carbon KA2S material containing less than 0.07 per cent carbon, in order to minimize any carbide formation.

The low-carbon KA2S alloy was used in making the $8^5/_8$-in. O.D. $^1/_2$-in. wall tubing and KA2B, KA2 plus 2–2.5 per cent Si, was used in the middle and lower portions of the superheater. This latter composition was recommended by the builder as being approximately ten times as resistant to sulphur corrosion from fuel oil as either KA2 or KA2S, and was therefore given preference over the lower carbon alloy.

Several different classes of so-called low alloy steels were installed in both installations in an attempt to learn as much as possible regarding the behavior of various alloys under the action of the high-temperature steam and at the same time find materials other than the expensive austenitic group. Aside from the saving in material cost involved in using these cheaper alloys, they are more readily fabricated into sound castings and tubing. This was illustrated by the delay and expense involved in the drawing and fabrication of the Delray superheater tubes and the pouring of the outlet fittings. It was impossible for the maker to draw and bend tubes long enough for the lower section of the superheater from the KA2B material. This section was finally completed by flash welding

TABLE I—PRINCIPAL PROPERTIES OF IMPORTANT ALLOYS USED IN TRENTON CHANNEL AND DELRAY INSTALLATIONS IN THE "AS RECEIVED" CONDITION

Physical Properties

Alloy No.	Tensile Strength Lb. per Sq. In.	Yield Point Lb. per Sq. In.	Elongation % in 2 In.	Reduction of Area, %	Remarks
1	85,000	25,000	40	40	Nirosta KA2
2	91,600	....	53 in 8 in.	59	KA2S
3	90,000	35,000	40	40	KA2B
4	68,000	....	4 in $1^1/_8$ in.	8	Rezistal 2C
5	137,000	118,000	25 in 1 in.	33	Used in turbine construction
6	78,000	45,000	25	40	$^1/_2$% Mo
7	140,000	122,000	16	50	4–6% Cr—1% W
8	110,000	76,000	32	65	14% Cr
9	....	....	..	..	Hecla ATV1
10	67,000	40,000	31	45	Era 131
11	225,000	210,000	11	33	Seminole Hard

Chemical Analyses

Alloy No.	C	Cr	Ni	Mo	W	Mn	Si	P & S
1	{0.16 max.	17.0	8	..	..	0.50	0.25	0.025 max.
	{	20.0	10				0.75	
2	0.06	17.6	9.2	..	..	0.53	0.57	0.02
3	{0.10	17.0	8.0	..	..	0.65	2.0	0.025
	{0.20	19.5	10.0				2.5	
4	0.23	17.5	9.0	..	..	..	1.6	0.03
5	0.31	0.35	3.10	0.34	..	0.72	0.32	0.06
6	0.25	...	...	0.50	..	0.75	0.36	0.035
7	0.39	5.20	...	..	1.10	0.46	0.25	0.015
8	0.25	14.28	0.28	..	..	0.52	0.34	0.015
9	0.47	11.84	36.32	..	..	0.24	0.23	0.01
10	0.17	0.24	...	0.84	..	0.71	0.24	...
11*	{0.45	1.20	...	..	1.75	0.35	..	0.05
	{0.50	1.45			2.25			

* V—0.20 to 0.25.

shorter tubes together. It was also necessary to recast the outlet fittings before sound ones were obtained.

Among these alloys that were placed in service were three castings made from 4–6 per cent Cr, 1 per cent W; one casting of 0.5 per cent Mo; a $5^1/_2$-in. O.D. length of 4–6 per cent Cr, 1 per cent W tubing; a valve body of Era 131, an English alloy (see Table I); and medium and high-carbon calorized steel; together with the nickel-chromium-molybdenum steel adopted by the turbine builder for all parts of the turbine subjected to high-temperature steam.

The 4–6 per cent Cr, 1 per cent W alloy which was developed to withstand the high-temperature corrosive service in the oil industry offered possibilities due to its creep resistance of 1 per cent in 100,000 hr. at a 6000-lb. per sq. in. stress, and its corrosion resistance properties. The 0.5 per cent Mo and Era 131 steels were recommended by English investigators as possessing good creep resistance properties. The nickel-chromium-molybdenum steel used for the turbine and throttle valve was selected as the result of investigations conducted by Thos. Firth and Sons, Ltd. at the request of The British Thomson-Houston Company, Ltd.

Typical analyses of all of the steels that have been discussed are given in Table I.

Some idea of the creep resistance of these various materials can be gained from the values of stress required to produce a 1 per cent creep in 100,000 hr. as given in Table II.

TABLE II—CREEP PROPERTIES

Part	Material	Temperature	Stress	Investigator
Tubing and Castings	KA2	1000	15,000	Norton
Tubing	KA2S	1000	12,500	White and Clark
Tubing and Castings	4–6 Cr, 1 W	1000	6,350	White and Clark
Casting	Era 131	1100	5,200	White and Clark
Bolts	Seminole Hard	1000	7,000	White and Clark
Castings	Ni Cr Mo	1000	5,900	White and Clark
Casting	0.5 Mo	1000	7,200	White and Clark
	0.43 C	1100	1,500	Norton
	0.42 C	1000	3,500	Norton
	0.20 C	1000	3,200	Norton

A few tubes of medium- and high-carbon calorized steel were installed in the Trenton Channel superheater to determine the degree of protection secured with aluminum coating. After the first installation of this material, 0.35 C steel tubes coated with aluminum were installed in the middle section of the Delray superheater, together with a like number of tubes coated with 18–8 and 12–14 per cent Cr stainless steel applied with a Schoop metal spray gun.

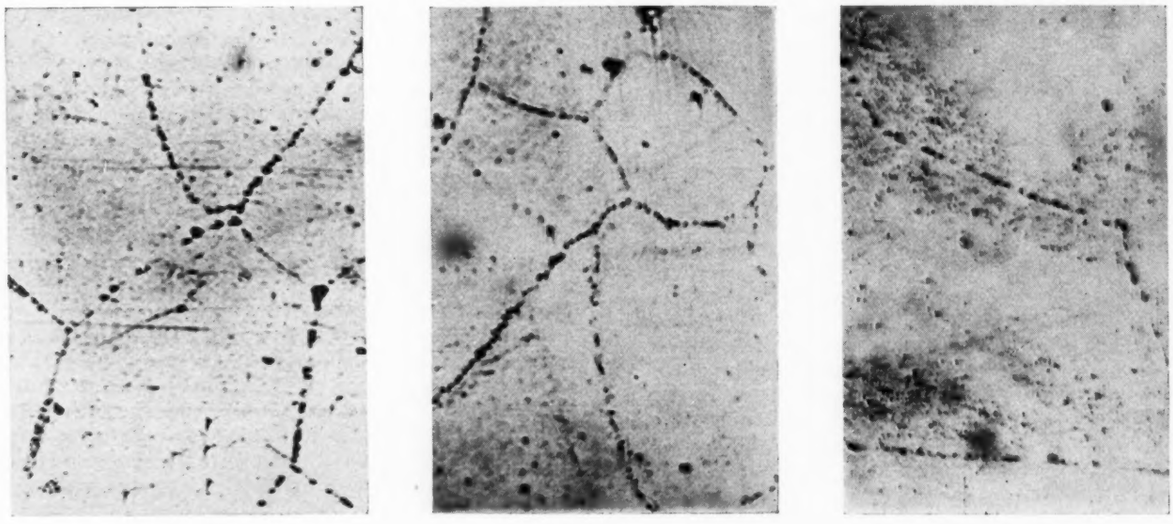
Bolts used for the joints in the cooler sections of the Delray superheater interconnecting piping were made from SAE 3140, while the remainder of the joints were made up with 18–8 bolting. Seminole Hard material was used for the joints in the piping system and metal gaskets were used for all the unwelded joints. Flanges for the welded joints in the pipe line were S.A.E. 3240, a low chrome-nickel steel.

The selection of materials for the turbine was left entirely in the hands of the turbine builder. They, working with the Brown-Firth Laboratories, selected as the result of time-yield tests (*8*) the nickel-chromium-molybdenum alloy, the analysis of which is given in Table I, for the turbine throttle valve, the high-pressure shaft packing case, the inner and outer high-pressure cylinders, and the forged rotor. The time-yield test on this steel at 1000 fahr. showed less than a 0.5 per cent extension during the first 24 hr. at a stress of 5,600 lb. per sq. in., and no further extension during the next 24 hr. A maximum design stress of 5000 lb. per sq. in. accordingly was used in the turbine design. The original interstage diaphragms were cast from the same material but due to the imperfect castings obtained, these were replaced with built-up diaphragms made from a 0.40 per cent carbon steel before operation with 1000 fahr. steam. The turbine nozzle partitions and wheel blading with the exception of the first-stage buckets, were made from a 0.25 per cent C, 14 per cent Cr, stainless steel. Hecla ATV1 containing 0.47 per cent C, 11.8 per cent Cr, and 36.3 per cent Ni was used for the first-stage blading. All of the shaft packing was made from forged modified monel. The interstage packing was later changed to a stainless steel at the time the original diaphragms were replaced. Nothing unusual in the way of materials was used in the low-pressure element.

With the exception of several parts, the careful attention that was given to the selection of the materials described has so far resulted in trouble-free operation. The results of examinations which have been made and changes necessary are discussed more in detail in the following sections of the paper.

Metallurgical Examinations

Results of both physical and microscopic examinations made on various materials from the two installations have shown evidence of slight changes. In no case, however, have these changes, loss in strength, or tendency toward embrittlement, progressed to such an extent that any consideration has been



Specimen 1
Removed in 1930, after 6,408 hr. service. Murakami's etch x 1800

Specimen 2
Removed in 1932, after 15,535 hr. service. Murakami's etch x 1800

Specimen 3
Removed in 1933, after 21,496 hr. service. Murakami's etch x 1800

Fig. 3—Photomicrographs showing chromium carbide precipitation at the grain boundaries of 18–8

given to replacement of parts. It is entirely possible that the changes which have been observed will progress at a much slower rate than has occurred during the initial period of operation.

Six different classes of alloy materials have been examined after varying lengths of service. These include wrought KA2 and KA2S and cast Rezistal; medium and high-carbon calorized steel; cast 4–6 per cent Cr, 1 per cent W; nitralloy; cast nickel-chromium-molybdenum used in the turbine; and Seminole Hard, together with several other bolting materials.

TABLE III—SERVICE PERIODS OF 18–8 ALLOY SAMPLES

Part No.	1	2	3
Date of Removal	1930	1932	1933
Steam Temperature	Hours in Service		
Below 900 fahr.	246	360	360
900 fahr.	916	1,471	1,471
1000 fahr.	1,732	3,254	4,068
1050 fahr.	337	438	438
1100 fahr.	3,177	10,012	15,159
Total	6,408	15,535	21,496

Three different sections of 18–8 material have been removed from the Trenton Channel installation. The first of these was a section of the 18–8, $5^1/_2$-in., $^3/_8$-in. wall tubing removed in 1930; the second was a similar piece removed in 1932; while the third section was a 2-in., $^1/_4$-in. wall superheater tube removed in May of this year. These parts were in service at various steam temperatures as shown in Table III.

The physical properties of these specimens are given in Table IV. Included, also, are the properties of the material in the "as received" condition which, unfortunately, were not obtained from specimens cropped from the identical tubes tested, prior to final fabrication. They were taken, however, from identical sections and are considered representative of the material before service.

Microscopic examination of the samples show evidence of carbide segregation at the crystal boundaries. A typical photomicrograph of each sample is shown in Fig. 3, which gives some idea of the extent to which this segregation has taken place. Each successive sample has shown a widening of the grain boundaries, although in no sample thus far examined has there been evidence of inter-granular corrosion.

In an attempt to express quantitatively the extent of deterioration which has taken place, the method used by Aborn and Rutherford was followed (*9*). This method consists of measuring the change in electrical conductivity caused by boiling the specimen in a modified Strauss solution. Materials which are subject to inter-granular corrosion show a great increase in conductivity after being heated in the solution. The samples were boiled for 48 hr. The first showed a 60 per cent increase in conductivity, the second a 260 per cent increase, while the third sample and the material in the "as received" condition showed no change. It is probable that the corrosion resistant properties have been restored in accordance with test data presented by E. C. Bain (*10*). This rather favorable result, as compared with troubles encountered elsewhere, is due, no doubt, to the absence of an actively corrosive fluid and partly to the fact that the operating temperature is slightly below the range in which carbide segregation is most pronounced (1200 to 1300 fahr.).

TABLE IV—PROPERTIES OF 18–8 ALLOY AFTER DIFFERENT SERVICE PERIODS

	Specimens			
	1	*2*	*3*	*4***
Tensile strength, lb. per sq. in.	95,100*	91,600*	113,000**	91,600*
Elongation, per cent	35	37	38.5	53
Reduction of area, per cent	36	54	57	59
Hardness, Brinell No.	148	152	202	143
Reduction in Izod impact value, per cent:				
At room temperature	5	17.5	68	0
At 1000 fahr.	19	11	12	0
Chemical Analysis, Per Cent				
C	0.06–0.07	0.09	0.05	0.05
Cr	....	17.4	17.4	....
Ni	....	8.6	8.2	....

* 21-in. pipe coupons, 8-in. gage length.
** $^1/_4$-in. A.S.T.M. standard tensile specimen, $^4/_{14}$-in. gage length.
*** "As received" condition.

The physical properties would indicate that the material is slowly becoming embrittled as evidenced by the increase in hardness and drop in impact value. These changes, however, have not been of sufficient magnitude to cause any concern. It is improbable that failure, should it occur, will ever take place without warning, as evidenced by the good corrosion resistant properties exhibited by the third sample. Development of special 18–8 alloys (10) to inhibit chromium-carbide segregation should make this material even more suitable for high-temperature steam use.

Examination of an unused flange, a valve body and a desuperheater, all made from cast Rezistal, showed that these castings contained inclusions and blow holes. The valve was removed after 6899 hr. of service, 5937 of which were at temperatures between 1000 and 1100 fahr. The desuperheater was removed after 6408 hr. of operation, 5246 of which were above 1000 fahr., because of cracks caused by a combination of thermal stresses and the poor metal. No comparison or conclusions regarding the suitability of this alloy can be made due to the evident unsatisfactory condition of these parts as received. The physical properties and chemical analyses are given in table V.

Of the two installations of calorized carbon steel, the first at Trenton Channel has been cut up and examined. The second, which consists of five-tube elements in the intermediate section of the Delray superheater has not been removed for examination.

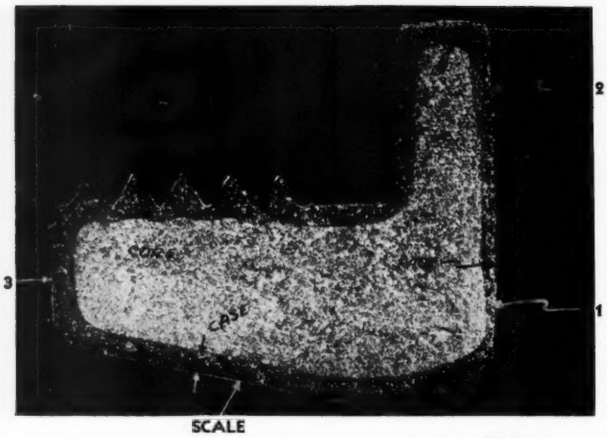
TABLE V—PHYSICAL PROPERTIES OF REZISTAL 2C CASTINGS

	Valve	*Desuperheater*	*Flange*
Tensile strength, lb. per sq. in.	67,400	21,800	68,300
Elongation, per cent in $1^1/_2$ in.	7	0	4
Reduction of area, per cent	3	0	8
Izod impact value, ft. lb.	27	7	11
Chromium, per cent by weight	18.7	15.9	17.5
Nickel	10.8	7.2	9.0
Silicon	1.2	1.25	1.6
Carbon	0.22	0.23	0.23

The Trenton Channel material, consisting of surface-treated 0.13 C tubing, 0.25 C castings, and 0.40 C forged headers, comprised a small superheating unit connected in series at the outlet of the original unit. The heating surface was composed of eight elements extended into the combustion chamber and directly exposed to flame impingement at their lower ends. This unit was removed after 3821 hr. of service, 3305 of which were above 1000 fahr., due to the excessive growth of the forged return bends at the lower ends of the furnace tubes. These tubes were subjected to surface temperatures as high as 1600 fahr. and to combined stresses, due to internal pressure and heat flow, as high as 3000 lb. per sq. in. Approximately 10 per cent of the calorized coating on the furnace tubes had disappeared and the remaining 90 per cent was quite brittle. The inside of the tubes was coated with magnetic oxide 0.04 to 0.08 in. in thickness, and measurements showed creep rates as high as 2 per cent per 1000 hr. The tubing and headers outside the setting were in good condition; measurements indicated no growth; the coating was apparently in a similar condition as when installed; there was little evidence of magnetic oxide formation, and physical properties had changed only slightly.

The surface of the calorized and sprayed Delray tubes is apparently in good condition except in several spots where a coarse granular appearance indicates a brittle condition. The tubes now have become coated with a $^1/_{16}$-in. layer of slag which protects the coating from attack. The development now being made to produce a more ductile aluminum coating and its application to low alloys possessing good creep properties offers possibilities for the adoption of this class of material for high-temperature equipment.

Information regarding 4 to 6 per cent Cr, 1 per cent W material received from several sources was to the effect that this steel had a tendency to embrittle when subjected to prolonged heating at temperatures ranging from 1000 to 1100 fahr. Inasmuch as several parts made from this alloy were in service



Designation	Depth of Case, In.	Vickers Brinell Hardness No.
1	0.012	470
2	0.028	560
3	0.036	550
Core	....	200

Etchant: 3 per cent nital—Magnification: 5 x

Fig. 4.—Macrograph of nitrided seat ring after 12,995 hours

at Delray and Trenton Channel, a valve of this composition was removed from the outlet of the Trenton Channel superheater for examination. The valve was of 600-lb. A.S.A. standard construction and had been in service for a total of 12,995 hr., 10,818 of which were at a temperature of 1100 fahr.

The test results showed that apparently the material in the valve body did not undergo embrittlement and that the long service at the high temperatures tended to increase the toughness and ductility. This statement cannot be made more definite as none of the valve material, before being subjected to service, was available. Comparison was made between supposedly similar samples supplied by the same vendor. Little reliance can be placed on the results of the tensile tests from the valve body, shown in Table VI, due to the presence of inclusions throughout the casting which made it impossible to obtain a sound test specimen.

The increased impact strength at 1000 fahr., the decreased hardness and reduced tensile strength of the valve material tend, however, to indicate an increase in toughness and ductility. The apparent change from martensitic to sorbitic microstructure is in agreement with the changes in physical properties. The valve material contained a somewhat greater amount of chromium and tungsten carbides than the material in the "as received" condition. In no sections of the valve casting examined, however, were grain boundaries outlined with carbides. This fact, together with the impact values obtained, indicates that noticeable embrittlement did not occur. The condition of the metal and the original low impact value, however, were considered unsatisfactory.

TABLE VI—PHYSICAL PROPERTIES OF 4-6 PER CENT CR, 1 PER CENT W VALVE BODY

	Material in "As Received" Condition	Material from Valve Body
Tensile Strength, lb. per sq. in.	139,800	94,200*
Yield Point, lb. per sq. in.	121,700	45,900
Elongation in 2 in., per cent	16	7
Reduction of Area, per cent	50	18
Izod Impact Value, ft. lb.		
Room Temperature	7	6
1000 fahr.	24	36
Brinell Hardness No.	278	200

* Contained small flaw, 5 per cent of cross-section.

Experience with nitralloy would indicate that it is unsuited for high-temperature valve trim. Continued service has resulted in scale formation and pitting of the surface of the trim of two valves installed in the Trenton Channel line. The trim in the first valve, removed after 6408 hr. of service, of which 5246 were above 1000 fahr., had a non-uniform case covered with a thin scale and a maximum Vickers Brinell No. of 700. Examination of the nitralloy rings from the Cr-W valve showed a condition of which Fig. 4 is typical. A coating of scale approximately 0.010 in. in thickness covered the contact faces of the rings which does not show in the illustration. The surface hardness values had dropped from 1000 Vickers Brinell Number to those shown under Fig. 4. These rings were fabricated in 1930 and had received a 24-hr. treatment; six hours at 1000 fahr. and the balance at 970. This material is supposedly stainless at steam temperatures in the 700 fahr. region, but examination of these samples would indicate that it cannot withstand the attack of dissociated steam at the higher temperatures.

Results presented by R. W. Bailey in a paper (*11*) before the Institution of Mechanical Engineers on the embrittling effect undergone by some nickel-molybdenum steels when subjected to stress at high temperatures led to an investigation of the material used in the high-temperature section of the turbine. This material definitely fell within the range of nickel and molybdenum content which Bailey stated was susceptible to embrittlement. Material for the investigation was taken from the original ninth-stage cast diaphragm. This piece had been in service for 656 hr. at temperatures not exceeding 250 fahr. and was therefore considered representative of the nickel-chromium-molybdenum turbine parts before service.

The result of tests conducted similar to those of Bailey, except at 1000 fahr., indicates that the turbine material is not subject to the sort of embrittlement that he encountered on wrought steels of nearly the same composition, stressed as high as 20,000 lb. per sq. in. at 842 fahr. The results of the impact values obtained on the notched $^1/_2$-in. round specimens in an Izod machine are given in Table VII. All of the samples showed an increase in impact value rather than a decrease.

TABLE VII—RESULTS OF EMBRITTLING TREATMENT ON CAST NI-CR-MO TURBINE MATERIAL

Embrittling Treatment	Impact Value at Room Temperature Ft. Lb.	Change in Impact Value Resulting from Treatment, Per Cent	Impact Value at 1000 fahr. Ft. Lb.
1. None	53	0	34
2. Heated at 1000 fahr. for 200 hr.	59	+11	34
3. Heated at 1000 fahr. for 200 hr. at 12,000 lb. per sq. in. notched prior to treatment	56	+ 6	41
4. Same as 3, except notched after treatment	60	+13	40

Small specimens suitable for hardness readings and microscopic examination were removed from the turbine throttle valve after 3809 hr. of service, 1450 of which were at 1000 fahr., and compared with the diaphragm material. The little difference found was not pronounced and may have been caused by difference in the heat treatment of the original castings.

Various bolting materials have been tried with different degrees of success. The material which has given the best results is a properly heat treated A.S.S.T. No. 5 chisel steel, having the composition given for steel No. 1 in Table VIII. This alloy possesses good creep resistance properties and a high tensile value at room temperature. Bolts made from this steel are given an oil quench from 1650 fahr. and drawn at about 1100 fahr. to give a Rockwell C hardness value of from 42 to 45. Threads are cut after heat treatment to prevent the formation of cooling cracks at the thread roots. Trouble experienced with quenching cracks has been eliminated by removing the decarbonized mill surface, prior to heat treatment. This steel is not entirely stable after prolonged service as is evidenced by a drop in impact value, hardness and tensile strength. The results of examination of four bolts, two of which were removed after 6408 hr. of service, 4278 of which were between 1000 and 1100 fahr., and two of which were removed after 10,575 hr., 7832 of which were at 1000 fahr., are shown in Table IX. Less joint maintenance has been experi-

TABLE VIII—CHEMICAL ANALYSES OF BOLTING MATERIAL

Steel No.	Trade Name	Chemical Analysis C	Cr	Ni	W	Mn	Si	Mo	V	P. & S.
1	Seminole Hard	0.45–0.50	1.25	...	2.0	...	..	..	0.25	Max 0.05
2	Rezistal, 2C	0.05	19.5	9.9	..	0.70	2.3	..	..	Max 0.01
3	Supertemp	0.36	0.52	...	0.94	0.90	..	..	..	Max 0.03
4	1722	0.45	1.40	...	0.77	0.50	0.71	..	0.28	...
5	D-1	0.08	1.17	...	0.97	0.25	0.28	..	..	...
6	SAE 3140	0.35–0.45	0.45–0.75	1.0–1.5	..	0.5–0.8	..	..	..	Max 0.05
7	Vibrac	0.48	1.28	2.59	..	0.62	0.15	0.59	..	Max 0.02

enced with this bolting notwithstanding its change in properties due to its high elastic and plastic properties.

Steel No. 2, although possessing good resistance to creep, was found to be subject to severe embrittlement and did not possess sufficient elastic strength to withstand the thermal stresses encountered in the warming and cooling of a steam line. One set of bolts made from Steel No. 3 required tightening once during 10,893 hr. of service and showed a drop in impact value of approximately 50 per cent. Steels 4, 5, and 6,

TABLE IX—PHYSICAL PROPERTIES OF SEMINOLE HARD BOLTING

	Group in Service 6,408 hr. (4278 hr. at 1000 to 1100 fahr.) Before	After	Group in Service 10,575 hr. (7832 hr. at 1000 fahr.) Before	After
Tensile Strength, lb. per sq. in.	214,000	213,000	225,000	163,000
Yield Point, lb. per sq. in.	204,000	202,000	210,000	....
Elongation in 2 in., per cent	11	12	11	14.4
Reduction in Area, per cent	36	37.5	33	42.5
Brinell Hardness No.	457	400	462	338
Izod Impact Value, ft. lb.	....	....	12.5	8.5

in the condition used, have required frequent tightening to compensate for creep. Bolts made from steel No. 7 were supplied with the turbine. Their behavior has been satisfactory except in the throttle valve bonnet joint where stresses have been too high. It is believed that with the new valve now installed this condition has been corrected.

Pipe-Joint Experience

Troubles encountered with bolted pipe joints have been many and varied. In the authors' opinion, it is doubtful whether with present materials bolted joints can be designed to give the same trouble-free operation at temperatures of 1000 to 1100 fahr. that has been experienced with present designs at 700 to 750 fahr. From experience gained, however, with the original joints at Trenton Channel, it has been possible to construct two joints that have now been in service for over 16,000 hr. at steam temperatures above 1000 fahr. without attention. Full strength welded joints appear to be the answer to the high-temperature jointing problem, although there is much to be learned regarding the behavior of weld metal under stress at high temperature and the weldability of desirable high-temperature alloys.

It was rather fortunate, in one respect, that the original joints at Trenton Channel were not made heavier than the 600-lb. A.S.A. flange standard as troubles were soon encountered which led to improvements in design. Some of the difficulties probably would not have been anticipated in the turbine installation at Delray had these joints been made more substantial. This original design led to the use of various joints which fall roughly into five classes.

Two types of stress, aside from stress due to internal pressure and bending moment imposed by change in position of a line, appear to cause most of the difficulty in high-temperature bolted joints. These are thermal stress caused by the temperature differential between the inside and outside of the joint and differences in coefficient of expansion of the joint materials, and creep stress caused by the plastic condition. In order to eliminate the thermal stresses, so-called temperature compensated joints were tried. These consisted of joints using 18–8 bolts and having spacers between the flange and nut of a material similar to Invar. The bolt and spacer lengths were so selected that any tendency to pick up or lose load was compensated for by the difference in coefficient of expansion. These joints failed due to the rather high stresses selected and failure to consider the plastic phase at the operating temperature.

The second class of joints used were similar to the original joints with materially increased flange and bolt dimensions. Two 5-in. joints in the Trenton Channel line, made up with the bolt stress limited to 10,000 lb. per sq. in., have been in service over 16,000 hr. These are Van Stone type with serrated facing, KA2 flanges, steel No. 1 bolting material and $^1/_{32}$-in. plain monel gaskets. The 900-lb. flanges in one joint were increased to $3^3/_8$-in. while the 1500-lb. flanges in the second joints were made $4^1/_8$-in. in thickness. All of the bolted joints in the Delray line, with the exception of the joints on either side of the superheater outlet valve, were made to either the 900- or the 1500-lb. A.S.A. standard. Leaks which occurred in two 8-in., 1500-lb. joints after 6795 hr. of service were due to plastic deformation of the gasket faces rather than to dishing of the flanges or creep of the bolts.

Full strength mechanically reinforced welded joints are in service in both installations. The mechanical reinforcement, consisting of collars over three Trenton Channel joints and backing up flanges on the Delray joints was added to prevent pulling apart should the 18–8 weld metal ever disintegrate due to inter-granular corrosion at the fusion zone. Additional time is needed to determine definitely whether such precaution is or is not necessary in 18–8 welds. It would appear from examination of the fusion zone of welding on the 18–8 tube removed from the Trenton Channel superheater, that the region affected by welding does not undergo any more rapid change than the parent metal; at least when under no stress. This particular welding was used to fasten lugs to hold the tube protecting tiles. These joints have given no trouble.

Another class of joint in service, embracing the Sargol and Sarlun, is seal-welded. The original Trenton Channel joints were provided with Sarlun welding lips, two of which were welded after trouble was experienced maintaining a tight-gasketed joint. During the 17,236 hr. of service it has been necessary twice to repair cracks which developed in each joint as a result of bolt elongation. The modified Sargol type joints, used in the interconnecting and outlet piping of the Delray superheater, where the steam temperature varies from 850 to 1000 fahr., have given no trouble.

The high stresses encountered in the Trenton Channel joints and a desire to obtain satisfactory joints for the 600-lb. flanges of the valve at the superheater outlet led to the design of the hairpin-type spring joint. The first of these joints installed at Trenton Channel consisted of springs, of hairpin shape, placed between the flange and one nut on each bolt. The springs were designed to maintain a unit gasket pressure of ten times the S.S.P. during the warming and cooling of the joint by compensating for the unequal expansion between flanges and bolts. The bolts were stressed to approximately 10,000 lb. per sq. in. and the outer end of the spring was stressed to about 17,000 lb. per sq. in. The joint was remade after 1532 hr. service and has since remained tight for nearly 15,000 hr. The temperature at the highly stressed outer portion of the spring does not exceed 600 fahr. with 1100 fahr. steam in the line. The two Delray joints which were designed with a maximum spring stress of 60,000 lb. per sq. in. leak when being placed in service due to water accumulation. They tighten up, however, when this water is evaporated. This design is not recommended because of the spring weight and cost. Its use was desirable in our case to prevent overstressing the valve flanges which were ordered to the 600-lb. standard before sufficient experience was obtained at Trenton Channel with this standard.

Creep

Troubles due to growth or creep of parts, with the exception of the difficulties encountered with the 600-lb. standard pipe joints, have been confined almost wholly to the turbine throttle valve. Excessive growth of the lower ends of the calorized superheater tubes at Trenton Channel caused their removal before failure occurred. Creep of other parts has been measured but in no case where changes have been observed is the creep occurring at an alarming rate.

The throttle-valve trouble has been caused by dishing of the bonnet joint flanges, with the result that it has been impossible to maintain a tight joint. The body itself has also exhibited changes amounting to creep rates as high as 3.5 per cent per 100,000 hr. based on measurements made during the last 6083 hr. of operation. This growth caused slight binding of the main disk on one occasion.

Measurements of parts of the turbine, other than initial readings, have not been obtained except in the case of the valve chest where a special measuring device was provided by the makers to determine the overall change in length. The changes measured have been insignificant. The last reading obtained at this location showed a slight decrease which would indicate warping. It is probable that excessive changes have not occurred in the turbine. The running characteristics have not changed and leaks have not been experienced at any of the bolted joints on the high-pressure cylinder.

The periodic measurements that have been made of the tubes in the Delray superheater are of rather doubtful value. Two types of readings are being taken from stainless-steel measuring points; diameters with micrometers and length measurements with a special 20-in. micrometer trammel. The close grouping of the tubes has made it impossible to obtain diameters other than at the top of the middle section where tube temperatures are in the neighborhood of 900 to 925 fahr. Where the length readings were taken, sag of the tubes caused by the resistance offered to expansion by the cast walls of the setting caused erratic measurements of no value as far as creep information is concerned. Changes in diameter of three of the 0.30 to 0.40 C, $2^1/_2$-in. O.D., $^7/_{16}$-in. wall, steel tubes and three KA2B, $2^1/_4$-in. O.D., 0.203-in. wall, alloy tubes observed during the last measuring period of 5005 hr. indicates that the steel tubes are growing at an average creep rate of 4.4 per cent per 100,000 hr. while the alloy tubes are growing at a corresponding rate of 5.3 per cent. The calculated design stress for the steel tubes was 2000 lb. per sq. in. and for the alloy tubes, 4300 lb. per sq. in. Measurements of the headers and fittings in the alloy sections have not been made since the equipment was placed in operation.

Changes of importance have not been observed at the point of maximum design stress of 6400 lb. per sq. in. in the 8-in. Delray pipe line or in any of the fittings in this system. Measurement of a section of $5^1/_2$-in. O.D. chrome-tungsten tubing after service in the Trenton Channel line showed no change after 7465 service hours. The measurements made on the original 18–8 Trenton Channel piping have not been of sufficient accuracy to indicate the small changes that have probably occurred under the low design stress of 3200 lb. per sq. in. Dishing of the bonnet flanges of the 600-lb. chrome-tungsten valve, removed from the Trenton Channel piping system after 12,995 hr., amounted to approximately 0.014 in. on the body flange and 0.011 in. on the bonnet flange. The contact faces of the main body flanges dished 0.004 in. on one end and 0.007 in. on the other.

It has been found in certain instances where diametrical measurements have been taken that it is desirable to take more than one dimension in the same plane. Part of the change which occurs may be due to relief of internal stresses not removed during fabrication causing the part to distort or to assume an out of-roundness in no way connected with creep. This fact should be kept in mind as well in the measurement of parts subject to bending stresses since changes may occur in the plane of the bending moment which are not shown because of improper location of the measuring points. In regard to the measuring points, welded stainless steel beads have been used to prevent scale formation detracting from the accuracy of subsequent readings.

Observations have indicated that higher design stresses could have been selected for certain parts of both installations. The original design was based on a combined stress which would keep the creep rate of the order of one per cent in 100,000 hr. This was probably too conservative as in certain parts of the installation, such as piping, creep tends to relieve high bending stresses, thereby dropping the combined working stresses. The so-called elastic stresses cannot, however, be entirely disregarded as it is necessary during start-up periods to consider the magnitude of forces set up at anchor points and at flanges.

Operating Experience

No unusual precautions have been found necessary in the operation of either the Trenton Channel or Delray installations. The turbine has received more than ordinary attention due primarily to the experimental nature of the unit rather than from any hazard connected with the use of 1000 fahr. steam. Major troubles have not occurred with either the turbine or the superheater. Experience with the Trenton Channel superheater and piping system has had to do more with pipe joint troubles already mentioned in some detail. The following remarks regarding operation, therefore, are confined to the Delray apparatus.

Operating a turbine with 1000 fahr. steam is little different from operating with lower superheat. The present starting cycle used in placing the installation in operation consists in starting with 700 to 750 fahr. steam and applying 30 per cent load to the turbine before the temperature is increased. The same procedure, in the reverse order, is followed in taking the unit out of service. It is believed that the use of higher temperature steam would tend to complicate the starting cycle because of large temperature differences which would exist in the turbine. It is the authors' opinion that units which may in the future be built for 1000 fahr. operation should be provided with either a low-temperature source of starting steam or a desuperheater in the turbine lead to prevent the occurrence of severe high thermal stresses during the starting period.

A clearance indicator mounted at the front end of the high-pressure cylinder showing the movement of the rotor relative to the casing has been used as a guide in determining a safe rate for changing load or steam temperature. The forged rotor, a smaller metal mass than the casing and in more intimate contact with the steam, is more responsive to temperature changes. Its movement is watched, therefore, to prevent going below a safe minimum axial clearance of 0.010 to 0.015 in. on the leading edge of the fifth wheel. No maximum rates of load or temperature change have been determined, but load has been applied at the rate of 1000 kw. per minute from 30 per cent to full load without producing vibration or a clearance change exceeding 0.045 in. Normally load is changed at a rate of 1000 kw. per 3 to 4 min. and temperature is changed at a rate of 100 deg. per hour. This last rate is an arbitrary one and might be exceeded without difficulty. Attention should be given to this detail of running clearance in any turbine designed to operate at high temperature or under rapidly fluctuating load conditions.

During the initial period of operation the steam temperature was increased in increments of 25 to 50 deg. above 900 fahr., allowing the unit to operate approximately one week at each temperature until 1000 fahr. was reached. During this period of operation growth of the throttle-valve packing sleeve occurred causing the stem to bind. The original semi-steel bushing was replaced with one having a nitrided surface and no evidence of growth has since been observed. Similar bushings in the five control valves were also renewed with nitrided parts as a precaution.

Recurring leakage of the throttle valve bonnet joint led to the procuring of a new and heavier valve casting.

Upon examination of the high-pressure cylinder interstage packing after 3809 hr. service, evidence was found of more than normal wear, caused, presumably, by the binding of the packing segments against the retaining pin which resulted in rubbing during starting. The outer high-pressure shaft packing which had been examined on previous occasions indicated a similar condition. Recent examination of the outer packing after being refitted and subjected to 7422 hr. additional service still shows wear, but not to the extent previously found. All of the packing is of the saw-tooth type made in rings of four segments each. The rings are loosely fitted into tee-slots and held in proper relation to the shaft by flat leaf springs which allow the packing segments to move outward in case of shaft deflection.

TABLE X—SERVICE HISTORY OF THE TRENTON CHANNEL AND DELRAY INSTALLATIONS

Service Hours of Trenton Channel Installation

Mar. 4, 1929 to Sept. 1, 1933

Steam Temperature	Hours
Below 900 fahr.	360
900 fahr.	1,471
1000 fahr.	4,420
1050 fahr.	438
1100 fahr.	16,311
Total hours in service	23,000

Load Duration—Delray Installation

Oct. 1, 1930 to Sept. 1, 1933

Load Per Cent	Hours in Service					
	700 fahr.	800 fahr.	850 fahr.	900 fahr.	950 fahr.	1000 fahr.
20	40	6	2	3	...	3
40	191	123	28	106	41	3,545
60	327	170	60	438	377	1,959
80	404	139	480	211	85	582
100	62	38	19	37	12	1,743

Total hours in service at 1000 fahr.— 7,832.
Total hours in service— 11,231.

Maintenance figures for the turbine are not in line with other turbines operating at lower temperatures because of the experimental nature of the unit. It has been inspected at frequent intervals and has received more attention in general than would normally be thought necessary. With the exception of the throttle valve and bushing replacements, no maintenance costs of an extraordinary nature chargeable to the high-temperature steam have been incurred.

Expense incurred in the maintenance of the superheater has been principally for replacing the small tube-protecting tiles in the lower radiant section. The excellent results obtained with these tiles cemented to the straight tubes in the Trenton Channel unit led to their use for protection of the curved radiant tubes in the Delray superheater. Trouble developed at the start in maintaining these tiles in place because of insufficient clearance between the ends of the blocks and relative movement between adjacent tubes which tended to push them from place. Insistence on the part of the manufacturer that operation should not be continued at outlet steam temperatures above 900 fahr. when any radiant tubes were unprotected led to a change in the method of insulating the back of the tubes. Tie bars, holding the tubes in groups of twelve, were added to reduce the relative movement of adjacent tubes and the tile shape was altered slightly to provide greater clearance between tiles. These changes have materially improved the service continuity of the refractory lining. At the present time, should a tile drop out of place during operation, the temperature is not lowered and the tube is allowed to remain bare until the next shut down.

Water collecting in the U-shaped tubes forming the furnace bottom has complicated the starting process somewhat. The procedure is to admit no steam to the superheater until after the fire has been started and temperatures of about 300 fahr. are indicated on the tube thermocouples located at the bottom of three arbitrarily selected tubes. The power-operated relief valve at the outlet is then opened to provide a sufficient circulation of steam to carry out any remaining water. Conditions are then satisfactory for admitting steam to the turbine for starting.

The Trenton Channel installation has now been operated for a total of 23,000 hr. and the Delray equipment has been operated for 11,231 hr. up to Sept. 1933. The hours of operation at various temperatures are shown in detail in Table X.

Concluding Comment

In summing up the experience recorded to date with the two high-temperature installations, the information that has been gained on various types of construction and the results of metallurgical examinations would indicate that the use of steam equipment at temperatures as high as 1000 fahr. is entirely feasible. It is safe to say that a plant could now be built to operate on 1000 fahr. steam and that reliable service could be expected. Although the authors may have appeared to stress the shortcomings and difficulties, it is not their intention to convey the idea that these are of a serious nature or in excess of the general run of troubles to be expected with any equipment of an entirely new and untried design.

It is not the purpose of this paper to present the economics of such a choice of steam conditions. In the authors' opinion it is doubtful whether such a selection could be justified if high-temperature resisting materials now available were used. Further metallurgical research may produce such materials at a much lower cost which will in the future give economic justification to the use of 1000 fahr. steam.

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Ninth Annual Conference on Welding

Purdue University announces its Ninth Annual Conference on Welding to be held at Lafayette, Indiana, on December 7 and 8, 1933. This conference will be held under the direction of the Engineering Extension Department and the Department of Practical Mechanics, with the manufacturers of welding equipment cooperating. The conference will include talks, exhibits and demonstrations, and is open to all manufacturers and welding shop operators of Indiana and neighboring states. Programs will be ready about November 25th.

Walter N. Cargill, 185 Devonshire Street, Boston, who is sales agent for The Air Preheater Corporation, has now been appointed by The Superheater Company, New York, as its sales agent in the New England states for stationary superheaters, economizers, furnace water walls and other Elesco steam plant equipment.

Supersaturated Steam†

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Supersaturation, or the failure of steam to condense when the saturated condition is reached in an expansion, has long been a matter of interest to engineers. This paper presents an account of an investigation of this phenomenon in which the principal objectives were the location of the Wilson line, which indicates the condition at which condensation actually occurs, and the measurement of the size of the drops which are formed when flowing steam condenses. It was found that in a simple convergent-divergent nozzle condensation did not occur until the steam had reached the condition approximately represented by the 3.5 per cent moisture line on the Mollier chart. It was concluded that supersaturation invariably occurred in the condensation of flowing steam, and that the superheated steam formula should be used to estimate the flow through nozzles of saturated steam.

APPLICATION to the flow of saturated or wet steam of the usual formula, based upon the assumption that condensation begins as soon as the saturation condition is passed in an expansion, results in a theoretical flow which may be smaller than the actual. This excess, at first attributed to experimental error, has been so conclusively demonstrated by the work of able experimenters that the correctness of the conventional theory of condensation is questionable.

The theory of supersaturation was proposed to explain this phenomena. It was suggested that steam in a rapid expansion from a dry or slightly superheated condition might not begin to condense when the saturated condition was reached, but might continue to expand as in the superheated region, thus becoming "supersaturated." Such a theory explains the excess flow encountered in the expansion of saturated steam through nozzles.

Flow of a fluid through a nozzle depends upon the product of its density and velocity at any given cross-section. The conventional theory of condensation requires that steam begin to condense when the saturated condition is passed in an expansion. The condensed portion of the steam gives up its latent heat, causing a decrease in the density of the surrounding medium. If the condensation should fail to occur, the latent heat would be retained, with the result that, for a given expansion, the density of supersaturated steam would be greater than that of wet steam. The velocity of the supersaturated steam would be less than that of the wet steam because the isentropic heat drop is less for a supersaturated than for an equilibrium expansion. The product of the velocity and the density, however, is greater for the supersaturated than for the wet steam, and hence the weight flowing through a given area is greater.

Need for further data on supersaturation in actual steam flow and the lack of information on condensation nuclei and drop size led to a two-year study in the laboratories of The Johns Hopkins University of the flow through nozzles of relatively low-pressure steam. The original object of this research was to investigate the condensation of steam in an effort to learn how and when this occurs, and to discover the conditions under which supersaturation actually exists. It was desired to locate by experimental means the Wilson line, which on the Mollier chart represents the condition at which condensation actually occurs in expanding steam at the termination of the supersaturated state.

Supersaturation has been studied by many investigators. In considering methods of attack, it appeared that Mellanby and Kerr (*25*)* had exhausted the possibilities of the weighed flow analysis. The optical method used by Stodola (*29*) to study flow in nozzles and by Thomas (*31*) to examine moisture in steam did not appear to have been utilized to the fullest possible extent, and the possibility that drop sizes might be measured by optical means made this method more attractive. It was believed that if the condensation point could be seen, the pressure at that point could be measured with a search tube and thus some positive knowledge of condensation conditions would be obtained, from which the supersaturation could be determined.

Theory of Supersaturation

Supersaturation is based upon the fact that the vapor pressure of a liquid at a given temperature is greater above a curved than above a plane surface. This can be understood by referring to Fig. 1 where a represents a molecule on a plane liquid surface, which is attracted by all of the molecules of the liquid within the radius p. Consider next the molecule b, on the curved surface at the right. This is attracted by fewer molecules than a because those molecules in the solid area are no longer present. At the same temperature, then, molecule b will be tied less securely to the surface than will a, and, conversely, a greater pressure in the surrounding atmosphere will be required to force b to remain on the surface. In other words, the vapor pressure is greater than that of a. Thus a water droplet, if sufficiently small, will evaporate if placed in an atmosphere of saturated steam. If, however, the vapor is supersaturated, or at a pressure greater than that corresponding to the temperature, equilibrium can exist between the vapor and the droplet when the pressure of the vapor is equal to the vapor pressure of the droplet. The conditions necessary for equilibrium between vapor and droplets were investigated by Lord Kelvin (*32*) and a formula to express these conditions was derived by von Helmholtz (*18*).

The fundamental supersaturation equation of von Helmholtz is

$$\text{Log}_e \frac{p}{p_s} = \frac{2\gamma}{RTDr} = \text{Log}_e S$$

† Contributed by the A.S.M.E. Steam Power Division for presentation at the Annual Meeting, New York, N. Y., Dec. 4 to 8, 1933, of the American Society of Mechanical Engineers.

* Numbers after proper names apply to references in the bibliography at the end of this paper.

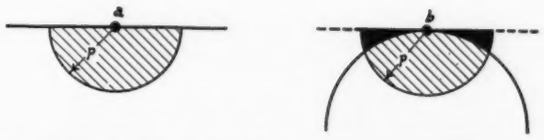


Fig. 1—Illustrating that at a given temperature vapor pressure of a liquid is greater above a curved than a plane surface

where p denotes the pressure in equilibrium with the drop of radius r at temperature T, and p_s is the saturation pressure at that temperature. D is the density of the liquid, γ the surface tension of the liquid in pounds per foot, and R is a constant from the $pv = RT$ relation of perfect gas. The ratio $\frac{p}{p_s}$, denoted by S, is known as the supersaturation ratio.

This equation gives the relation which must exist between the actual pressure and the saturation pressure at the existing temperature if a drop of radius r is to be in equilibrium with the vapor about it. If this ratio is lowered the droplet will evaporate. If it is raised, the droplet will grow.

It will be seen from the equation that the logarithm of the supersaturation ratio varies directly with the surface tension and inversely with the absolute temperature and the radius of the drops. Surface tension decreases with increasing temperature and finally vanishes at the critical condition. Thus there can be no supersaturation at the critical condition. Conversely, surface tension increases with decreasing temperature and the supersaturation ratio for a given drop size increases as the temperature is lowered.

The equation also indicates the need for a nucleus upon which condensation can occur. If r is made very small, S must be very large, and finally, in the limiting case, when $r = 0$, $S = \infty$. Thus in order for a pure vapor to condense, there must be some nucleus of finite radius.

The search for such a nucleus motivated early workers in this field. Aitken at first concluded that dust particles always served as nuclei, but he rejected this conclusion upon finding that condensation occurred with filtered, dust-free vapor. Von Helmholtz believed that ions were the nuclei upon which condensation took place.

C. T. R. Wilson found three distinct types of nuclei. Working with air saturated with moisture, he found that a small expansion caused condensation upon the relatively large particles of dust which were present in the air. With dust-free air he discovered that at a higher expansion ratio condensation occurred upon ions. Wilson's "cloud chamber," well known to physicists, is based on this feature of the phenomenon.

He was able to trace the path of ionizing rays by causing them to pass through an illuminated chamber and photographing their tracks, which are droplets of water condensed upon the ions formed by the ray.

With air freed both of dust and of ions, Wilson found that a sufficiently high ratio of expansion would invariably cause a heavy condensation in the form of innumerable very small droplets. The nuclei responsible for this ultimate condensation, investigated at great length by Barus (*6–8*), were seemingly inexhaustible, and appeared to form an essential part of the water vapor, for they could not be removed by any process. The conclusion reached by both Barus and Wilson was that these nuclei are associated or agglomerated molecules.

While the existence of supersaturation has been demonstrated by the work of the authorities mentioned above, a supersaturation limit, or Wilson line, based on theory alone is not acceptable. There are so many uncertain variables in the von Helmholtz equation and so many assumptions in its derivation that the validity of results based upon it is open to question. An experimental investigation of the condensation conditions is necessary to determine the actual supersaturation limit, and the following sections record such an investigation.

Description of the Apparatus

The apparatus, Fig. 2, was designed to provide a nozzle with a transparent side through which the expanding steam could be observed with the aid of an intense beam of light passing axially through the nozzle. Observation at right angles to the illuminating beam was essential. Referring to Fig. 3, steam entered through the main valve A and passed through a 2-in. line into the superheater, B, consisting of a 6-in. steel pipe within which was placed a copper coil supplied with high-pressure steam through valve C. Evaporation of the entrained moisture was the principal function of the superheater, but it could also be used as a de-superheater by closing valve C and the drain valve, and opening valve D, admitting to the coil cold water which was discharged to the sewer.

Steam passed from B into the tee, F, which had at one end a glass port, E, and at the other the nozzle assembly, G. In the side of F was inserted a standard thermometer well. The nozzle, rectangular in cross-section, was formed by two polished brass blocks bolted to the sides of a cast-iron channel. The glass plate which constituted the top of the nozzle was clamped tightly to the channel, with rubber gaskets above and below to prevent leakage.

Inlet pressure was measured by a Bourdon gage or a mercury manometer. The pressure connection, a 1/32-in. hole, was located at the center of the bottom of the channel, 1 in. above the throat of the nozzle. The steam from the nozzle passed through a second tee into a 2-in. line leading to a condenser in which a vacuum of 25 in. of mercury could be obtained. Valves in the discharge line permitted the back pressure to be raised to any desired value.

The static pressure of the steam at any point along the axis of the nozzle could be measured with the aid of a brass search tube, of 0.125 in. inside diameter. The steam pressure was transmitted through six holes, 1/32 in. in diameter, in the form of a piezometer ring, located about 14 in. from the end of the tube. The search tube was soldered to a larger tube which passed through a stuffing box and connected by means of flexible rubber tubing to a Bourdon gage and a mercury manometer. A hand-wheel and screw permitted the search tube to be moved along the axis of the nozzle, and the location of the pressure measuring holes could be found by a scale fastened to the frame. The back pressure was measured by a mercury manometer.

Illumination was provided by a carbon arc, the light from which was concentrated by a pair of lenses and introduced through the port E along the axis of the nozzle. A screen was usually used to keep the light from hitting the bottom of the nozzle, and a blue filter could be interposed between the arc and the nozzle if needed. When full illumination was desired, the search tube was removed and in its place was in-

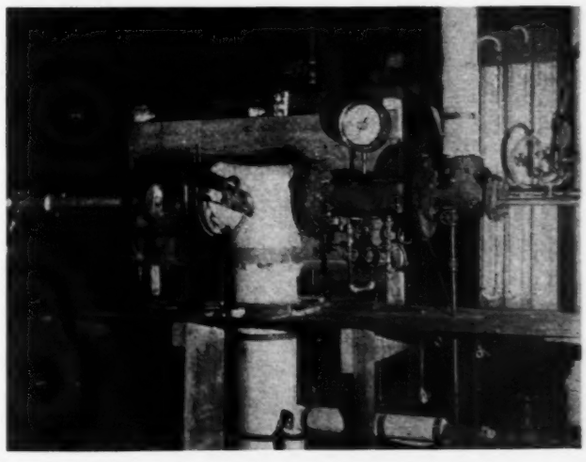


Fig. 2—Apparatus used in investigation

stalled a glass port through which the light from a second arc entered. This light could be focussed with a concave mirror into a sharp beam to study one portion of the nozzle or into a broad ray to illuminate it completely.

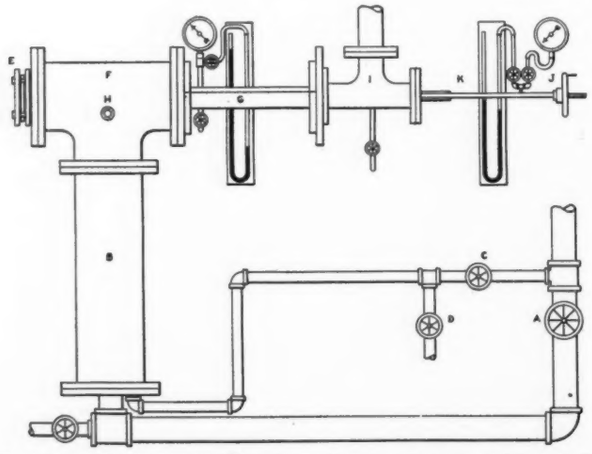
Method of Measuring the Supersaturation Ratio

When the apparatus was put into operation it was found that the intense light from the arc enabled the condensation point to be observed. The entering steam, superheated by throttling from the boiler pressure, was quite transparent, and the occasional drops of entrained moisture were easily seen. When condensation took place, however, the arc light was scattered by the great number of very small drops which formed in the steam, and a dense bluish mist was visible. As shown in Fig. 4-*A*, condensation occurred along a relatively sharp curved line. There was a distinct and unmistakable change in appearance from the transparency of the dry supersaturated steam to the blue cloud which indicated the presence of minute water droplets.

In determining the condensation pressure, the apparatus was allowed to run until it was thoroughly warm and the entering steam quite dry. A pressure traverse of the nozzle was then made by means of the search tube. When the piezometer ring on the search tube reached that portion of the nozzle in which condensation was occurring, the arc was turned on and the experimenter was able to estimate by visual observation the point at which the search tube left the supersaturated region and entered the wet. The static pressure at that point was assumed to be the condensation pressure. When the traverse was completed the condensation region was re-explored several times to check the pressure determination. The pressures thus obtained were plotted against nozzle length.

The method of determining the condition of the steam at the condensation point is based upon the assumption that the expansion through the throat of the nozzle is isentropic. This is not strictly true, for some losses are present, but those which occur before the throat is reached are small. The expansion to the throat of the nozzle used in this work was rapid and continuous. The fluctuations in pressure, which are responsible for a large part of the losses, occur after the condensation point has been reached. It is probable, therefore, that the losses to the condensation point do not at the most exceed 1 or 2 per cent of the isentropic enthalpy drop.

If isentropic expansion is assumed, the condition at the condensation point can be estimated from the Mollier chart by following the entropy line on which the initial state point of the steam is located. The condensation condition is the



A, inlet valve; B, superheater; C, superheater inlet valve; D, cold water valve; E, port; F, tee; G, nozzle assembly; H, thermometer well; I, outlet connection; J, search tube connection; K, search tube

Fig. 3—Diagram of apparatus

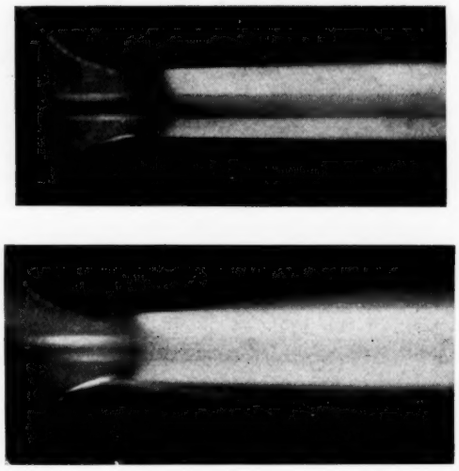


Fig. 4-A (top)—Flow through nozzle No. 1. Illumination confined to plane of search tube. Fig. 4-B (bottom)—Search tube in place, entire cross-section illuminated. Initial conditions 30 lb. per sq. in. gage, 300 fahr., back pressure 16 lb. abs.

intersection of that entropy line and the line representing the pressure at which condensation is observed. Since the conventional Mollier chart is based upon equilibrium conditions, the supersaturated condition cannot be represented correctly upon it. For this reason a revised Mollier chart was prepared. Fig. 5, a portion of this chart plotted on a large scale, shows the method of locating the condensation point. Point 1 is the initial condition, determined by measuring the pressure and temperature of the incoming steam. Line *ab* is the conventional wet steam line in thermal equilibrium for the pressure *pc* at which condensation is observed and *Ab* is the supersaturated line for the same pressure.

Steam, expanding isentropically from point 1, crosses the saturation line at point *S* but remains dry and supersaturated until it reaches a condition represented by point *A*. At that point condensation takes place and thermal equilibrium is almost instantaneously restored, which action is represented by the constant enthalpy line *AB*. The condition of the wet steam is thus represented not by point *A* or *a*, but by point *B*. If the expansion is not exactly isentropic, the friction and other losses will reheat the steam and raise slightly the enthalpy of point *B*.

It is evident that in a given expansion there is a distinct loss in availability because of this isenthalpic change from the supersaturated to the wet condition. If *H* is the isentropic enthalpy drop from the saturation line to the wet steam line *ab*, ΔH is the portion rendered unavailable because of the increase in entropy attendant upon condensation. It will be shown later that condensation takes place between the 3 and the 4 per cent moisture lines, for which condition the loss in availability remains sensibly constant at about 2 B.t.u. Since the isentropic enthalpy drop from the saturation line to this condition is approximately 50 B.t.u., the loss in availability amounts to some 4 per cent of that enthalpy drop. This loss is probably an important factor in the lower nozzle efficiencies found with wet steam than with superheated steam.

Martin's original definition (*23*) indicates that he intended the Wilson line to represent the condition of supersaturation at which condensation must occur in an expansion, that is, point A in Fig. 5. Since this requires a Mollier chart upon which the supersaturated pressure lines are present, it seems advisable to change this definition slightly, because the designer usually has at his disposal only the conventional chart. The Wilson line is therefore the loci of the points which indicate the condition of steam when condensation has just occurred, and when thermal equilibrium is re-established at the limit of supersaturation.

Since the supersaturation ratio is defined as the ratio of the actual pressure at a given temperature to the saturation pressure at that temperature, it is necessary to calculate the temperature of the supersaturated steam at the condensation point. This may be done by using the thermodynamic relations for superheated steam.

The Experimental Work

After it had been found that the condensation pressure could be measured with reasonable accuracy, the first feature to be investigated was the variation of that pressure with varying initial conditions. Using a simple convergent-divergent nozzle form, a series of measurements was made in the manner outlined above. Inlet pressures varied from 11.0 to 75.0 lb. per sq. in. abs., the range in which turbine condition curves usually cross the saturation line on the Mollier chart. Above the latter pressure the incoming steam was too wet for satisfactory observation.

From the curves plotted it was noticed that at the point where condensation occurs there is an abrupt halt in the fall of pressure. After the condensation point is passed the expansion continues as before. This unexpected feature was at first dismissed as an error in the manometer reading but it was repeated with such consistency that it must be accepted as an actual occurrence. A similar irregularity in the pressure-expansion curve was noticed by Prof. C. A. Robb in his work on recompression in nozzles, carried out at The Johns Hopkins University in 1931–32, but not yet published. It is probably due to the fact that the rapid increase in the specific volume of the steam, caused by the liberation of the latent heat of the condensed moisture, is not compensated by the increase in velocity and so must result in an increase in pressure, or in sustained pressure with increasing nozzle areas.

The pressure-distance curves showed that the steam invariably over-expands and then recompresses to the back pressure. When in recompression the steam reached the pressure at which condensation originally occurred, a dark spot appeared in the nozzle, (see Fig. 8A) to be followed once more by the familiar blue of the scattered light if the pressure again fell below the condensation value. The cause for such

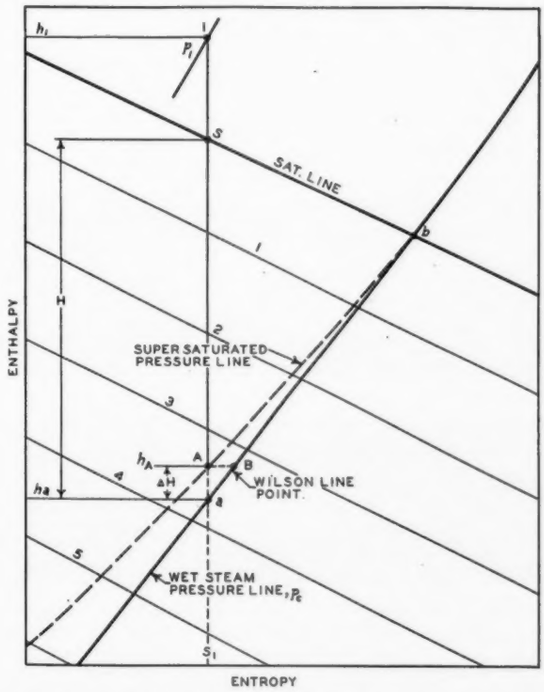


Fig. 5—Portion of revised Mollier chart showing method of locating condensation point

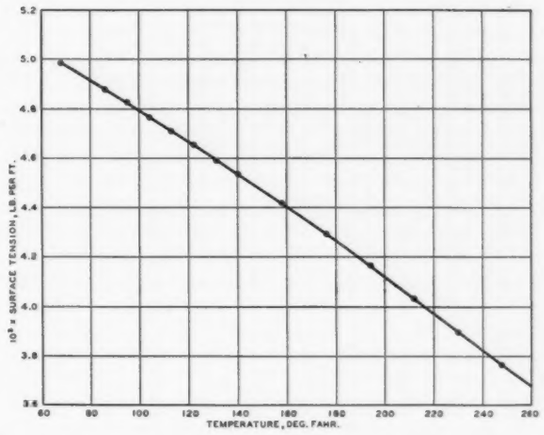


Fig. 6—Variation with temperature of surface tension

dark spots was the absence of droplets in the dark region. This disappearance of the droplets when the steam pressure was raised above the condensation value is evidence in favor of the supersaturation theory.

The data from the tests on nozzle No. 1 are tabulated in Table 1, which also contains the results of the calculations of the supersaturation ratio and the droplet radius for each condition. On Fig. 11, a revised Keenan Mollier chart, the condensation points found with nozzle No. 1 are located. The condensation points lie between 3 and 4 per cent moisture lines, and the line which is faired through them will be referred to as the Wilson line.

Table 1

Summary of Results of Tests on Nozzle No. 1

Point	Test No.	Pabs	t_1	Cond. Pres.	t_2	S	r, x 10^8, cm.
A	50 - 1	64.7	303	34	198.4	3.05	6.69
B	45 - 2	59.7	297	31	190.4	3.29	6.39
C	40 - 2	54.8	292	29	188.4	3.22	6.57
D	35 - 2	49.7	307	22	176.4	3.17	6.86
E	30 - 2	44.7	303	18.7	164.4	3.56	6.46
F	25 - 4	39.7	302	16.1	158.4	3.54	6.58
G	20 - 2	34.7	309	11.5	135.4	4.49	5.90
H	15 - 2	29.7	286	11.9	144.4	3.69	6.63
I	12.5-1	27.3	295	9.4	128.4	4.31	6.19
J	11 - 1	25.9	295	8.75	126.4	4.34	6.24
K	5 - 3	20.0	289	6.3	113.4	4.54	6.25
L	2.7- 1	17.5	295	5.3	112.6	3.89	6.97
M	0 - 1	14.4	270	4.4	94.4	5.51	5.87
N	0 - 3	12.8	285	3.3	84.4	5.64	5.95
O	0 - 2	11.3	283	2.9	82.4	5.30	6.17
S	Stodola 71.		Sat.	38.2	303	3.1	

In Fig. 7 the supersaturation ratios at various temperatures are plotted against those temperatures. A mean value of the drop radius, calculated by the von Helmholtz equation, is about 6.2×10^{-8} cm., which agrees with the values of Wilson, Powell and Stodola. If this value is substituted in equation of von Helmholtz, we have:

$$\text{Log}_e S = \frac{2\gamma}{D \times 86 \times T \times \dfrac{6.2 \times 10^{-8}}{2.54 \times 12}} = 1.15 \frac{\gamma}{D \times T} \times 10^7$$

Taking the proper values of γ the surface tension, from Fig. 6, and of D, the water density, from Keenan's steam tables, and solving for S at various temperatures, curve Y in Fig. 7 is obtained. This curve is a fair representation of the experi-

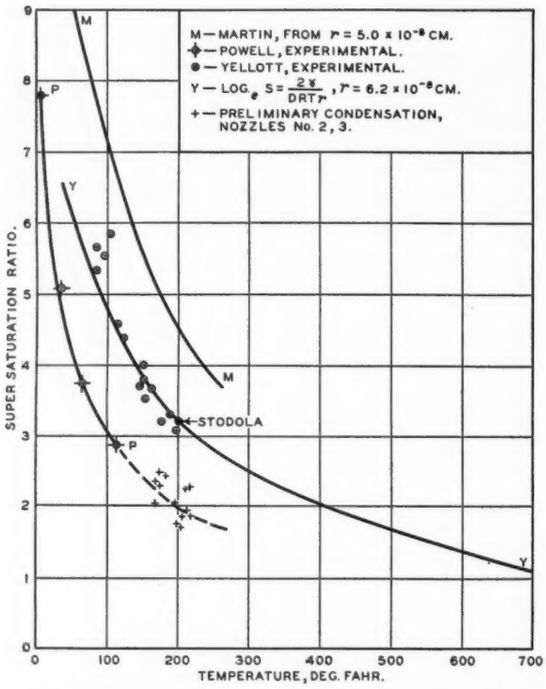


Fig. 7—Determination of supersaturation ratio at the Wilson line

mental points, since as many lie above the curve as below it, and a reasonable number lie directly on it. Curve *P* presents data obtained by Powell in his experiments, and curve *M*, values derived by Martin from his substitution of Callendar's value of *r* in the von Helmholtz equation. The results of the present investigation lie between those of Martin and Powell. The Wilson line as plotted also lies between their versions of the line, being closer to that of Martin.

Several interesting features of steam flow were discovered with nozzle No. 1. Recompression and the breaking away of the jet from the nozzle walls, predicted by Stodola (*29*, p. 93), were seen and photographed. In Fig. 8A the steam breaks away from both sides of the nozzle during recompression, and then re-expands to fill the nozzle, while a second recompression is evidenced by a second dark band. In Fig. 8B, the steam breaks away from the sides, but instead of returning to both walls, it continues down one side. This condition was very unstable, the jet alternating rapidly from one side of the nozzle to the other.

The observation of liquid water in steam was fully discussed by Thomas (*31*) and his work is substantiated by this investigation. It is possible to see drops of water in flowing steam, and the absence of moisture can be detected by the transparency of the steam. The light scattered by the steam No. 2, had a rounded inlet identical to that of No. 1, but a 1.0 molecules is so faint that it can be seen only against a perfectly black background, and hence dry steam appears transparent. The moisture entrained in the entering steam appears as relatively large drops, a few hundredths of an inch in diameter. As the steam is accelerated through the nozzle the large drops are broken up into much smaller droplets in the manner explained by Soderberg (*28*).

Summarizing the results so far presented, it is very improbable that any condensation will occur in the expansion of steam through a convergent-divergent nozzle of the type used in these tests until the steam has reached the condition approximately represented by the region between the 3 and 4 per cent moisture lines on the Mollier chart. When this region is reached, condensation apparently takes place on a vast number of tiny nuclei. The radius of the drops thus formed appears to be about 6.2×10^{-8} cm. When the steam in recompression again reaches the pressure at which condensation occurred, most, if not all, of the droplets seem to re-evaporate, appearing again if the pressure once more falls below the condensation value. Only blue light, completely plane polarized when observed at right angles to the incident light, was to be seen in the nozzle, so it is highly probable that there is no growth of the droplets as they pass through the nozzle.

The effect of supersaturation upon the flow of steam has been treated in detail by Stodola (*29*), Goodenough (*16*), and others. It may be concluded that supersaturation always occurs in the expansion of saturated steam, and for that reason the formula for superheated steam should be used to calculate the flow of saturated or slightly wet steam through nozzles. The actual effect of supersaturation in turbine operation is small, but, as has been pointed out previously there is a certain loss of availability caused by the increase of entropy which accompanies condensation and the establishment of thermal equilibrium. This loss may amount to as much as 4 per cent of the isentropic enthalpy drop from the saturation line to the Wilson line.

It was suggested by Prof. J. H. Keenan of the Stevens Institute of Technology, that nozzle No. 1 be replaced by another designed to give a less rapid expansion in the region where supersaturation occurs. The nozzle chosen for this purpose, in. straight section was interposed between the convergent and the divergent portions. This design produced the desired effect, for there was a rapid expansion through the rounded section, followed by a relatively slow drop in pressure through the straight throat. Additional expansion and recompression took place in the diverging portion.

The condensation which occurred in nozzle No. 2 differed radically in appearance from that encountered with No. 1. Observations of the flow through nozzle No. 1 showed that there was a distinct and relatively sharp curved line, concave toward the high-pressure end, which marked the beginning of condensation. A line of demarcation was thus provided between the transparent superheated steam and the misty wet steam. With nozzle No. 2 the condensation curve again appeared and the pressures measured at that curve for varying initial conditions were found to lie on the Wilson line. The term "ultimate condensation" will be applied to that which occurs at the Wilson line to distinguish it from the "preliminary condensation" which is about to be discussed.

The concave curve in nozzle No. 2 was preceded by a slight condensation which began as a trace of bluish haze and rapidly became more dense as the ultimate condensation curve was approached. Fig. 9 shows a photograph of the flow in nozzle No. 2, obtained by focussing the light from the arc at the

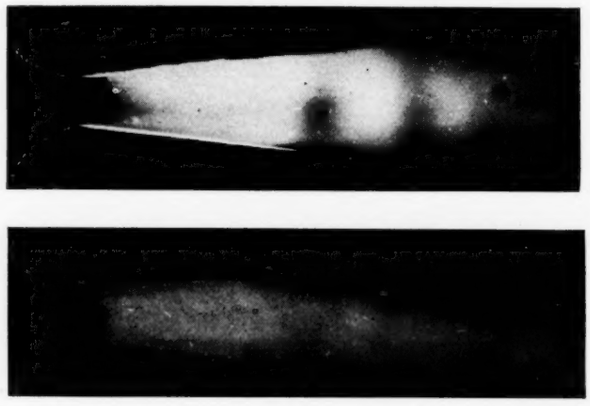


Fig. 8-A (top)—Flow through nozzle No. 1 completely illuminated. Initial conditions 20 lb. per sq. in. gage, 287 fahr., 15 lb. abs. back pressure. Dark bands indicate recompression above condensation pressure with evaporation of droplets. Fig. 8-B (bottom)—Taken after raising pressure to 35 lb. gage and 23 lb. abs. back pressure. Steam flow breaks away from one side of nozzle

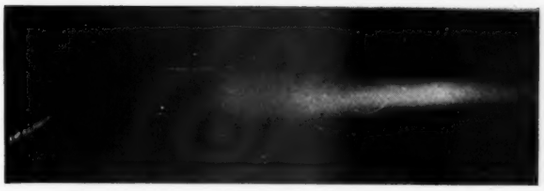


Fig. 9—Flow through nozzle No. 2, illuminated from low-pressure end by sharply focussed beam. Preliminary condensation can be seen before the curved line denoting ultimate condensation. Initial conditions, 28 lb. per sq. in. gage, 288 fahr., 15 lb. abs. back pressure

low-pressure end into a sharp beam. The preliminary condensation can be seen, and the curved line which denotes ultimate condensation is also visible.

In order to study this preliminary condensation, of which no trace had been found in nozzle No. 1, a series of tests was made as before, with inlet pressures ranging from 10.0 to 45.0 lb. per sq. in. gage. Pressure-distance curves were drawn and the data were plotted on a revised Mollier chart, from which it is evident that while ultimate condensation occurs approximately at the Wilson line, preliminary condensation appears to take place at points scattered about the 2 per cent moisture line. Because of the nebulous character of the earliest traces of the preliminary condensation, it is difficult to measure the exact pressure at which it begins. This difficulty accounts for the wide variations in droplet radii noted.

The existence of preliminary condensation raised some interesting questions. Stodola found no traces of such condensation, nor did the theoretical investigators consider the possibility of its existence. Up to the present time it has been assumed that supersaturation, if it existed at all, would continue until the Wilson line was reached, when condensation would occur and equilibrium would be re-established. Dust or other foreign particles in the steam would cause the type of condensation mentioned above, but particles large enough to act as nuclei would also scatter light with visible intensity before any condensation occurs. No such particles were seen in any of the tests.

It was hoped that preliminary condensation could be proved to occur upon ions, in which case the conventional theory would be vindicated. In order to study the possible electrification of the droplets, nozzle No. 2 was replaced by No. 2 *B*, made of bakelite with brass plates set into the straight sections to act as electrodes. When the steam was flowing and condensation was occurring a potential of 110 volts d.c., was connected across the electrodes. There was no apparent change in the character of the condensation, nor did reversing the polarity of the electrodes have any visible effect.

It was decided to apply another test. If preliminary condensation occurred on ions, increasing the number of ions should increase the density of the mist which indicated condensation. A similar experiment had been performed successfully by Wilson and Thomson. The most prolific source of ions which could be obtained was the spark from an induction coil. An insulated wire was led into the nozzle and so arranged that the spark could jump from the wire to the electrodes or to the bottom of the nozzle. When the coil was in operation a strong spark resulted, but there was no visible effect upon the condensation.

The factor controlling the type of condensation to be expected under various conditions may be a function of the rate of change of pressure with time. Tests carried out on nozzle No. 3, a simple rounded orifice, lend support to this theory. A series of tests was made with this nozzle using inlet pressures up to 40.0 lb. per sq. in. gage, and the back pressure was varied in each test.

It was found that the nature of the condensation in the jet varied with changes in the back pressure. If the steam expanded to a pressure below that of ultimate condensation, for the given initial conditions, the jet appeared as in Fig. 10. There was no preliminary condensation and the concave ultimate condensation curve of nozzle No. 1 was again visible. In such expansions there was no color other than the blue and the general nature of the condensation was similar to that found in nozzle No. 1. The jet expanded freely, bending first toward one side of the channel and then toward the other. The wavy outlines of the jet corresponded to the oscillations in the pressure-length curves. When the inlet pressure was raised to 40.0 lb. per sq. in. gage, the steam expanded to fill the entire channel and the dark bands due to recompression above the ultimate condensation pressure were quite distinct.

When the back pressure was raised until the ultimate condensation pressure was not quite reached during the expansion, the appearance of the jet changed completely. The well defined wavy outlines disappeared and the initial blue changed to a whitish blue, indicative of larger droplets. This condensation was apparently an intermediate type, being neither preliminary nor ultimate, but resembling each in some particulars. The pressures at which this intermediate condensation took place were slightly above the pressures at the Wilson line.

When the back pressure was raised to a still higher value, preliminary condensation occurred.

The type of condensation which occurred in nozzle No. 3 for any given inlet conditions could be varied among the three types mentioned above by varying the back pressure. The nature of the condensation was apparently a function of the velocity of the steam and of the duration of the condensation.

Results and Conclusions

The primary object of this investigation was to check the location of the limit of supersaturation, which, on the Mollier chart, is known as the Wilson Line. The secondary object was to determine the size of the water droplets formed by condensation from the supersaturated state, as their size may have some bearing on the erosion of the low pressure blades in steam turbines.

The Wilson line was located by measuring the pressures at which condensation occurred in an illuminated nozzle. A series of such measurements, covering the range of 10.0 to 75.0 lb. per sq. in. abs. in which turbine condition curves cross the saturation line, resulted in a number of points, through which the Wilson line was drawn. This will provide working data for turbine designers.

The Wilson line lies between the 3 and 4 per cent moisture lines on the Keenan Mollier chart.

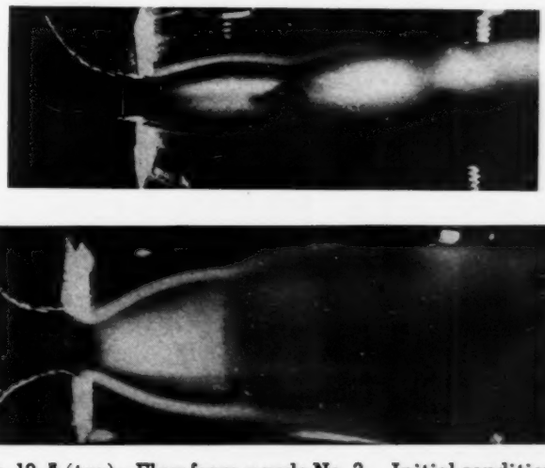


Fig. 10-A (top)—Flow from nozzle No. 3. Initial conditions, 25 lb. per sq. in. gage, 16 lb. abs. back pressure. Fig. 10-B (bottom)—Showing flow when inlet pressure was raised to 40 lb. Jet expands to fill entire channel. Dark bands caused by recompression above ultimate condensation pressure

The radius of the droplets which are formed when condensation occurs at the Wilson line is approximately 6.2×10^{-8} cm., a value determined by the von Helmholtz equation and substantiated by the blue color and complete plane polarization of the light scattered by the droplets.

The theory of supersaturation is verified for rapid expansions through simple convergent-divergent nozzle forms, for not only do the droplets appear at the pressures theoretically predicted, but also they disappear under recompression conditions in a manner which can only be explained by the supersaturation theory.

It was found that the behavior of steam in the illuminated nozzle could be seen clearly, and the phenomena of shock, recompression, and the breaking away of the jet from the nozzle walls were observed and photographed.

A second series of experiments on modified nozzles revealed that under certain circumstances condensation could occur before the Wilson line is reached in an expansion. The upper limit of this preliminary condensation region is close to the 2 per cent moisture line on the Mollier chart. Due to the difficulty in distinguishing the first traces of preliminary condensation, the experimental points obtained in the study of this type are too widely scattered to permit definite conclusions to be drawn. Evidence indicated that the velocity of the steam in the condensation region is the controlling factor.

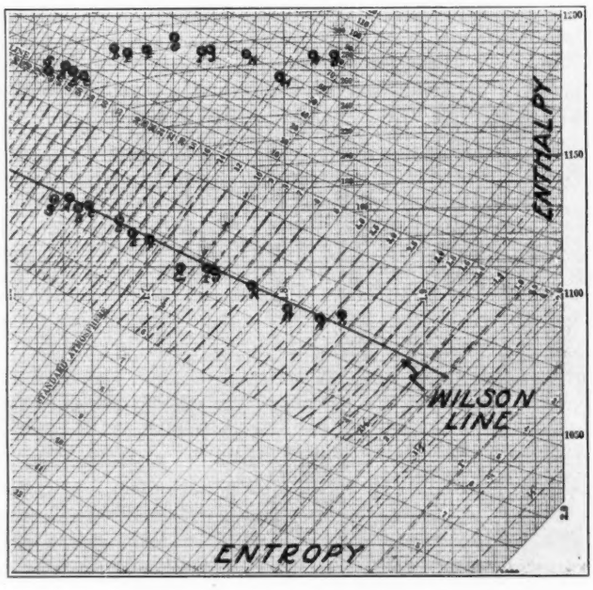


Fig. 11—Location of Wilson line. Results of tests on nozzle No. 1

With nozzle No. 1, the evidence is reasonably conclusive that there is no growth of the droplets during their passage through the nozzle. With nozzles Nos. 2 and 3 it was found that the drops which are formed in preliminary condensation grow very rapidly from about 10.0×10^{-8} cm., their original radius, to a magnitude comparable to the wave length of red light, about 6.0×10^{-5} cm. in radius. If, however, the preliminary condensation is followed by ultimate condensation, the first droplets cease to grow when the latter occurs, probably because all of the available moisture is acquired by the vast number of nuclei which become effective at the Wilson line. It may be concluded that, beyond those present in the dry steam, no additional nuclei are needed to effect complete condensation. As yet no explanation can be given for the existence of this preliminary condensation.

Acknowledgments

This research was carried on by the author at the Johns Hopkins University during two years of graduate study in mechanical engineering, under the direction of Prof. A. G. Christie, who rendered invaluable assistance in the experimental work and in the preparation of this paper. The author wishes to acknowledge his indebtedness for the helpful contributions of President J. S. Ames of that University, of Drs. A. H. Pfund, R. W. Wood and R. B. Barnes of the Physics Department, and of Associate Professor J. C. Smallwood of the Mechanical Engineering Department. Prof. J. H. Keenan of the Stevens Institute of Technology offered many valuable suggestions, and his interest is appreciated.

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Patents*

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PART XIII

Interference Procedure (Continued)

The present article continues the discussion of the involved interference procedure. In this article, Mr. Ramsey takes up the proofs required and gives examples of difficulties arising, such as originality, ultimate facts to be proven comprising conception, disclosure and reduction to practice. He analyzes and points out the distinction between "actual" reduction to practice and "constructive" reduction to practice.

Testimony

WE HAVE traced the interference procedure through the state of interlocutory motions and appeals therefrom. We are now ready to consider the taking of testimony to establish the proofs of the case and to analyze the same of the points which must be proved in order that a party may win.

If a Motion to Dissolve is granted and the Motion to Amend is denied, then the interference is terminated and each party goes his own way, the theory being that there is no common patentable subject-matter.

Where Motions to Dissolve have been denied and the claims are held to be patentable or where Motions to Amend have been granted and the new suggested claims are patentable, the interference proceeds.

Where the interference is continued on patentable subject-matter, one of two things happens. If it is a two-party interference and the junior party does not take testimony, then the senior party is not required to take testimony because his record date in the Patent Office, being earlier, stands as a bar to the junior party, since the junior party took no testimony to overcome this date. Under these conditions, the Examiner of Interferences awards priority to the senior party. If the junior party's Motion to Dissolve raised the question of the senior party's right to make the claim or that the senior party's disclosure is inoperative or any other point on which if the senior is defeated still leaves patentability to the junior party, the junior party may appeal from the final decision of the Examiner of Interferences. The theory of this appeal is based on the fact that if the junior party's contention is correct, he is entitled to the patent because there is some fact of record why the senior party has not completed the invention in issue before the junior party filed.

Assume that the interference is proceeding and that a Motion to Dissolve has been granted, but a Motion to Amend has also been granted. Where this happens, a period of time, usually twenty days, is allowed within which the new claims must be added by one or both parties. Since opportunity had been given to oppose the admission of new claims when the Motion to Amend was heard, no opportunity is given to oppose these new claims a second time by a Motion to Dissolve. Therefore, the new claims stand. If both parties copy these new claims into their cases within the period permitted, then the interference goes on as though these claims had been the original counts of the interference. Dates for taking testimony are set. First comes a date for the testimony-in-chief of the junior party; next comes the date for testimony of the senior party; and last comes the date for rebuttal testimony of the junior party.

Some time before the date for taking testimony expires, the junior party gives notice to the senior party of the place where testimony will be taken and also gives notice of the names of the witnesses whose testimony is to be taken. This notice must allow the opponent one day to arrange to attend and sufficient time to make the trip to a place where testimony is to be taken. Ordinarily, arrangements to take testimony are made between counsel so as to allow each party sufficient time to get ready to appear at the place where testimony is taken.

The Rules of the Patent Office require the witnesses to be sworn or affirmed before some officer competent to administer an oath, usually a notary public. The Rules of the Patent Office also require that the testimony be taken down on a typewriting machine as it is given by the witness. This is rather a slow procedure because it is in most cases impossible to transcribe on a typewriting machine as rapidly as the ordinary witness talks. It is accomplished by the witness stating a few sentences and then waiting for the typist to write down what has been said. This system has the advantage of giving an immediate visual record of what is being said so that if an error occurs, it may be promptly picked up and corrected. The parties may, by agreement, however, take the testimony in shorthand which is transcribed into typewriting later. This ordinarily is not satisfactory because court stenographers are seldom available and errors may occur. It may be difficult to correct these errors because the parties may not agree as to what the witness said.

If either party has a legal objection to a question which has been asked, he places his objection upon the record by dictating it to the typist. The witness then proceeds to answer the question as though the objection had not been made. This often results in padded records in that a great many things get into the record which really do not belong there, and in squabbles between attorneys, many pages of the record may be taken up by statements of the attorneys which are no part of the testimony. This adds to the expense of the proceeding.

After the direct testimony has been finished, the opponent has a right to cross-examine the witness. If for some reason, this opportunity is denied, testimony of the witness will be stricken from the record. It has happened that the direct testimony has been finished before lunch and that the witness would not come back after lunch, claiming to have been ill. In that particular case, the testimony was stricken from the record. If under cross-examination or where an adverse witness is on direct examination, the witness refuses to testify, the officer before whom the testimony is being taken may certify

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to the questions which have been asked and the attorney may obtain an order from a United States District Judge, requiring the witness to appear in Court. The matter may then be thrashed out before the Court as to whether or not the witness should be compelled to answer. The Court has authority to refuse to compel the witness to answer or to order the witness to answer. If the witness declines to answer when ordered to do so, he is in contempt of Court. Also, where it becomes necessary to use adverse witnesses, the witnesses may be subpoenaed through a subpoena issued by a United States District Court, commanding the witness to appear at a designated place and give testimony.

Testimony which varies seriously from the preliminary statement will not be considered. The purpose of the preliminary statement has been pointed out as being a paper of estoppel to the effect that the inventor makes a skeleton outline of his case at a time when he has no knowledge of his opponent's case or his opponent's dates. If his proofs do not conform to the statements which he has made in the preliminary statement, he should explain why. In other words, if he has alleged very early dates in his preliminary statement, but is unable to prove any of these dates, then on the face of things, it looks as though he did not tell the truth when he swore to his preliminary statement and this weakens his proofs. In any case, he is bound by his preliminary statement as to the earliest dates which he can prove. He will not be permitted to establish any date earlier than that defined in his preliminary statement. If he does take proof to establish earlier dates, this testimony may be admitted, but it will only be considered as having proved the date alleged in the preliminary statement even though the actual proofs may ante-date the preliminary statement by some time. Under these conditions, the applicant should make an effort to amend the preliminary statement as soon as he discovers the error in order that the preliminary statement may conform with the testimony. If the Patent Office allows the amendment the earlier date will be considered, otherwise not.

The uncorroborated testimony of the inventor is not sufficient to establish his case. It is not necessary, however, that the corroborating witness should be able to describe every feature of the invention. It is sufficient if the witness thoroughly identifies the invention so that it is unmistakable that he is testifying about the invention defined by the issue. This rule of full corroboration, does not apply to the date of conception because the inventive idea may occur to the inventor at a time when he is not able to disclose the invention to others. Therefore, he alone knows of this particular fact. He may, however, be supported in his oral testimony on conception by sketches which he makes at that time, and, furthermore, some one may have seen him sketching at the time even though he did not disclose what he was drawing until a later date. Any witness who testifies to his acts at that time, will not directly corroborate conception but such testimony will be considered as establishing the fact that the inventor was at least doing work at that time which might be a sketch of the invention. As to other features of the completion of the invention, however, the inventor must be corroborated.

Joint inventors are recognized as a single entity and the uncorroborated testimony of joint inventors is usually not sufficient to establish their case. In other words, if there are no witnesses to the joint invention for the junior party other than the inventors themselves, then the senior party will ordinarily win.

Where an inventor fails to appear and testify in his own behalf, the inference is usually unfavorable. Where, however, he has assigned his entire invention and is not friendly with the assignee, then the failure to call the inventor is not ordinarily regarded as raising any presumption against the owner of the application. Failure in any case to call important witnesses whose knowledge in the matter has been developed in the taking of testimony and which witnesses are available, always raises an unfavorable inference, and tends to discredit testimony which has been given. This general rule, however, is not to be considered as requiring an undue amount of accumulative evidence. If twenty-five people know of the facts concerning an invention, it would not be necessary that all should testify. It would be sufficient if a reasonable number testify to the facts.

Originality

One of the troublesome grounds frequently encountered in interferences is "originality," that is, one party claims that he disclosed the invention to the other who took it for his own use and tried to patent it. The question of originality cannot be carried outside of the parties to the interference. In other words, if it is a two-party interference, the Patent Office will not permit either party to testify that the invention was made by a third party. The reason for this is that the contest is between the two parties on the question of priority and that testimony to the fact the invention was made by a third party would not go to priority of invention by either party to the interference, but would go to the question of patentability which is not an issue in an interference case.

The cases of originality are many and varied in fact and circumstance. It sometimes happens that an inventor will disclose a broad invention to another party who will pick up the broad idea and make a specific invention on the broad idea. It sometimes happens, although it is rare, that an invention will have been disclosed by A through an outside party, B, that is, the original inventor A discloses and discusses his invention with party B who later discusses this same invention with another party, C. The last party, C, may file an application on the invention. If the first party, A, files an application and gets into interference with C and the proofs can be established that the party C did not originate the invention, but that he got it through B from A, the party A would win the interference. The mere fact that circumstances afford an opportunity for the party B to derive his invention from the party A is not enough. It is necessary to prove actual disclosure to the second party, mere possibilities are not ordinarily sufficient.

There have been a very few rare cases where a patent solicitor has filed an application on an invention similar to a client's and an interference has been declared. Under these conditions, the patent solicitor has the burden of proving his good faith regardless of when his application was filed and the Courts will very closely scrutinize any action of a solicitor or attorney which is antagonistic to his client's interests. The Courts will not permit him to profit by any information which he has obtained at his client's expense.

Some years ago a patent solicitor filed an application for a client and later filed an application for himself on the same invention. An interference was declared and the patent solicitor moved to dissolve on the ground that his client's application disclosed an inoperative structure. The question of originality was never raised. The Patent Office promptly disbarred this solicitor from practicing.

On the question of originality, as in other questions in interference proceedings, the presumption is in favor of the one who filed first, and the party second to file must offer convincing testimony to overcome this presumption. Occasionally, circumstantial evidence will be relied upon to strengthen the proofs of the junior party on originality, as for example, where the junior disclosed the invention to a company and then one employed in the company worked out the same idea in a similar device. The circumstances surrounding such a disclosure may properly raise the presumption that the invention came from the junior party. Of course, if the senior party can prove that he was working on the invention before the disclosure was made by the junior party, then the senior party will win the interference.

A very troublesome and difficult feature of originality is where a broad idea is suggested by one to another. It is a very common expression to hear some one say, "I invented so and so

years ago and I now see that it has been made a commercial success." Sometimes it happens that the party speaking did actually make and abandon the invention. Usually, however, the party making such a remark merely had the broad idea and the one who really made the invention and carried it into a commercial success went far beyond the broad idea and had many serious and troublesome problems to solve before the invention was really completed. It should be borne in mind that the mere idea or realization that the solution to a problem would be desirable is but the suggestion of a problem and not the solution thereof. It is merely an idea and not an invention. Many people conceived the idea that it would be desirable to fly, but it remained for the Wright Brothers to solve many of the basic principles necessary to produce sustained flight. The mere idea that it would be desirable to have pictures sent over a wire to accomplish television does not in any way advance the science of communications and is not in any sense an invention. Therefore, in order that the question of originality may arise, it is necessary that a complete mental concept of a patentable invention must be disclosed.

It is difficult to lay down any broad rules which will fit every case involving this question of originality. Conflicts frequently arise between employers and employees. The inventor may go to an artisan for the purpose of hiring him to construct the new machine and when the machine is completed, the artisan sometimes files an application on his own behalf. Under these circumstances, the general rule is that the presumption is in favor of the employer on the theory that the employer brought the invention to the employee and that the employee merely applied the skill of his art in the production of the working machine. Here again, the circumstances and conduct of the parties often helps to indicate which is the first and original inventor. The old doctrine of "he who is silent when he should speak" is often applied as a test. For example, where an employer instructed the employee to mark the article "Patent Applied For" and the employee did so without protest, it was held that his failure to protest raised a strong presumption that the employer was the real inventor.

In connection with this employer and employee doctrine, it must be remembered that each case depends upon its own facts and where the employee goes further than the mere skill of his art and makes an actual invention over what has been disclosed to him by his employer, the employee is entitled to the benefits of his own invention and is entitled to a patent thereon. This relationship between employer and employee is now being discussed merely from the standpoint of originality and not from any other standpoint. We have already discussed the relation between employer and employee as established by contractual relations and in the present discussion that phase of the law is not being considered.

The purpose of an interference is to determine the question of priority, and, therefore, testimony must be directed to this end. Testimony will not be considered which is directed to a public use or to the fact that the invention was made by a third party. The Patent Office occasionally will grant permission to take testimony on the question of operativeness, where this question is very involved and cannot be accurately determined from the disclosure of the application. This kind of a point often arises in connection with inventions relating to arts wherein the behavior of substances is peculiar such as in the manufacture of glass, or in connection with certain alloys in the metallurgical art, or in calculating machines or other complicated arts and mechanisms.

The Patent Office, in rare cases, may permit testimony to be taken on the right to make the claim. This testimony is analogous to testimony on operativeness. In both of these cases, the witnesses testify as expert witnesses, that is, they testify as to the behavior of substances or mechanisms which they have observed in operation. Machines embodying the structure in question are built, operated and examined by persons skilled in the particular art and their testimony is not directed to priority but is directed to the removal of an obstacle to the junior party's right to a patent, namely, if the senior party can be disposed of, then the way is clear for the junior party to win the interference. The Patent Office and the Courts have stated that these questions on operativeness and right to make the claim may properly be raised in an interference proceeding since they are ancillary to the question of priority.

Ultimate Facts to Be Proved

There are three principal ultimate facts to be proved by the taking of testimony to establish priority, namely conception, disclosure and reduction to practice.

Conception

"Conception" is sometimes not capable of very strong proof because usually corroboration thereof can only be coupled with disclosure. Circumstances may be such as to lead to the conclusion that the inventor's testimony on conception is true even though he cannot be corroborated. For example, if two engineers are discussing a problem one evening and no satisfactory solution is arrived at and they meet the next morning and one of the engineers has made an invention which solves the problem, it is obvious the invention must have been conceived between the time of their parting the night before and the time of their meeting the next morning.

Disclosure

The next important ultimate fact is "disclosure," namely, the circumstances surrounding the explanation of the invention by the inventor to some other party. Usually, the date of disclosure can be supported by corroborating witnesses. Some times, however, the witnesses are dead and other means of proof are required. For example, if the disclosure was made by the way of a signed sketch witnessed and dated by the deceased party, the inventor might testify to the circumstances surrounding the making of the sketch and then other witnesses may be called to prove the signature and date on the sketch as being in the handwriting of the deceased. Usually, there is more than one disclosure. The invention is frequently disclosed at different times to several people and such disclosures may not be all on the same date. Where this occurs, it is well to prove the several disclosures because it strengthens the fact that the inventor had the idea and was telling about it, and while the Patent Office may not accept the earliest disclosure as having been proved as of the date specified, it may accept a later date for some other disclosure, which later date may be sufficient.

The next and very important ultimate fact is "reduction to practice."

Reduction to Practice

Two types of "reduction to practice" are recognized, namely, "actual" reduction to practice, that is, where the invention has been actually embodied in a full size working machine; and "constructive" reduction to practice, which is the filing of an application disclosing an operative device. While as a matter of fact, actual reduction to practice is probably of more value to the public interest, so far as the Patent Office procedure is concerned, there is little difference in weight of evidence between an "actual" reduction and a "constructive" reduction.

Actual Reduction

The Supreme Court of the United States has held that an invention on a process is reduced to practice when it has been successfully operated; the invention on a machine is reduced to practice when it has been built and used; the invention of a composition of matter is reduced to practice when it is compounded; and that the invention on an article of manufacture is reduced to practice when it has been made in its complete form.

It has been held that where devices, though complete, were not satisfactory, that such devices did not constitute

reduction to practice. It has also been held that the mere construction of a machine without any test thereof is not a reduction to practice. The reduction to practice requires not only the making of a machine, but the successful testing thereof. A machine may be very crude, but, nevertheless, may be a reduction to practice provided it is successfully operated.

The mere manipulation of a device without accomplishment of any result has been held not to be a reduction to practice. For example, where six type bars had been constructed for a typewriting machine and these bars were manipulated without the use of paper or a printing ribbon in the typewriting machine and the inventor testified that he was convinced that the invention was complete, it was held that this was not a reduction to practice. If the inventor had gone a little further and tested the type bars in a practical way against a piece of paper, he would have completed the reduction to practice.

Where, after a machine has been tested and it was further used and the machine broke, such breakage did not defeat the fact that it was a reduction to practice. While ordinary breakage will not defeat reduction to practice, circumstances may arise where breakage will defeat this end, for example, where breakage occurs before a test is finished. The invention in question was a part of a car coupler and this part was made of brass and an attempt was made to test the coupler with a train of cars in a freight yard, but upon the test, the part comprising the new feature broke before the test was completed and it was held that the mere embodiment of the part in a piece of brass which did not stand up under the test was not a reduction to practice.

It is not necessary for the reduction to practice to be made by the inventor. The reduction to practice may be made by an authorized agent of the inventor. For example, if the inventor is working in a factory, some other workmen may embody the invention in its useful form and test it. The test by the authorized agent is equally as good as a test by the inventor himself. However, it has been held that a reduction to practice by an unauthorized agent is not sufficient. For example, where an inventor attempted to sell his invention to a company and he failed in his negotiations, but the company subsequently, for its own purposes, built, and successfully tested the device without the consent or knowledge of the inventor, it was held that this test did not inure to the benefit of the inventor. It has also been held that an accidental use is not a reduction to practice. In an automobile construction, including an open passageway, a car was provided with a passageway that was closed by a cap. The cap was accidentally lost and the machine was operated some time without knowledge of the loss of the cap. It was held that this operation did not help establish any test of the invention.

Ordinarily, a so-called "model" will not be accepted as demonstrating reduction to practice. Models are usually on small scale and are not capable of performing the actual work for which the machine is intended. However, where the machine is built full size of materials that ordinarily might not be used in actual practice, but which materials are sufficiently strong to be used to demonstrate the machine, such a construction, when tested, may be a reduction to practice. Where a machine or device is crude and not adapted for practical use, even though some tests are made on such a machine or device, it does not ordinarily result in a reduction to practice. Such a demonstration is usually considered as an experiment.

The reduction to practice of the invention must, of course, include all the elements called for by the counts of the interference. If some of the elements are lacking, it is obvious that the demonstration does not cover the complete entity for which the parties are contesting, and, is, therefore, not a test of the invention in issue.

The general weight of authority is that reduction to practice to be of benefit to the inventor must occur within this country and that work done outside of the country does not count as a reduction to practice in this country. This doctrine applies even where the invention was originally conceived and disclosed in this country, and where the inventor himself went abroad and completed the actual device and tests abroad and installed the apparatus abroad. However, when the inventor comes to this country, and he has actually tested the machine abroad, he brings into the country the completed invention and his arrival in the country is ordinarily regarded as the date of the completion of the invention within the United States.

Tests Necessary to Establish Actual Reduction

As a general rule, a test is required as one element of a reduction to practice. There is an exception to this rule, however, and that is, where devices are so simple that a mere inspection of the devices establishes the fact that they are capable of performing the intended function. Where this happens, an actual test is not required. An example of cases where tests have been held to be a necessary part of a reduction to practice are the following: a typewriting machine, a roller bearing, an electric circuit protector, a garment hook, a bottle cap, a printing plate and a rail anchor for a railroad rail. In cases where tests were not required are a cloth covered horse collar, a ticket holder for theatre tickets, a clamp for holding a safety blade, an envelope and devices of this kind. It may be definitely stated that even where a device is simple, it is by far the safer procedure to make and test one of the devices.

The sufficiency or degree of the test is important because it may determine the distinction between a successful demonstration and a mere experiment. It has been held that where a roller bearing was not put into practical use but which was tested by hand to see if it would run smoothly that such a test was a mere experiment and not sufficient to be a reduction to practice. The successful use of a machine at a later time will not convert a previous experiment into a reduction to practice. In a case where an experiment has been tried at an early date, which experiment did not include the actual use of the apparatus, it was held that the actual demonstration of the same apparatus at final hearing in the Patent Office did not convert the first test into a reduction to practice.

Commercial use is not required as a test for reduction to practice; it is sufficient if the test actually demonstrates the practicability of the machine. A shop test which operates under working conditions is sufficient. A shop test, however, is not sufficient where working conditions cannot be simulated. For example, a shop test of a railroad rail anchor intended to prevent longitudinal movement of the rails was held not to be a reduction to practice because actual working conditions of the rail anchor were not established in the shop test.

It has been held that a tire fastening device was not fully tested by placing the tire on a wheel and bouncing the wheel upon the floor, for the reason that such a test would not demonstrate the practicability of the device when the wheel was actually supporting the load of the car in a road test.

Where a device is tested successfully under working conditions, such a test is sufficient even though mechanical changes may be required before the device is in commercial form. In connection with a drinking cup test, which cup was adapted to be used once and then destroyed, it was held that the making of such a cup and filling it with water, which it successfully retained, was the proper test.

Where an attachment was made for a gear cutting machine to cut curved gear teeth and the machine was operated idly without actually cutting a tooth, such a test was held not to be a demonstration of the operativeness of the device.

The test of a sprinkler head for an automatic sprinkler which functioned properly, but which did not meet the requirements of the certain insurance companies, was, nevertheless, held to be a reduction to practice.

While no definite rule may be laid down, it may be said, however, that the test must be sufficient to completely demonstrate that the device is capable of successful operation.

Constructive Reduction

As has been stated, "constructive" reduction to practice occurs where an application for patent is filed that discloses an operative patentable invention. Constructive reduction to practice grows up on the theory that the invention is completed when it is fully disclosed in a specification and drawings that have been established by the Patent Office as embodying patentable subject-matter. It seems somewhat anomolous that a full size set of working drawings accompanied by a full description is not considered a reduction to practice, while if the same description and drawings were embodied in an application for patent, they become a constructive reduction to practice on the date that the application is filed in the Patent Office. The probable reason for this distinction is because where the drawing and description are actually filed in the Patent Office, it shows the intent of the inventor to benefit the public through his invention by getting a patent thereon, so that at the end of seventeen years the public will be in full possession of the invention. Whereas the mere making of drawings and writing a description is no evidence that the inventor intended to benefit the public by his invention because the drawings and the description may become buried and he may never have gone further, so that the whole thing may not be any more than an abandoned idea. This theory, however, is not entirely satisfactory because even though these working drawings and description be published in a publication, still they may not constitute a reduction to practice. The fact remains, however, that it is a fiction of patent law that an application for patent is a constructive reduction to practice.

A divisional application takes the date of the parent application for construction reduction where the parent application clearly disclosed the invention in issue. This same rule applies to continuing applications. It will be remembered that a continuing application is one which takes part of the material from the parent application and adds other material to it. If the entire disclosure of an interference is in the original application and is carried into a continuing application, then the date of constructive reduction to practice is that of the parent application. If, however, the complete invention in interference was not disclosed in the original application, but is disclosed in the continuing application, the date of construction reduction to practice will be that of the continuing application.

Some years ago, there was a case in the Patent Office where the original application on a very complicated machine was criticized by the Patent Office for mechanical defects, and in the meantime, the inventor had conceived an improved form of the machine. A second application was filed disclosing the improved form of the machine, which embodied a broad invention disclosed in the first application. The first application was then abandoned and the second application was prosecuted for some years until the attorney was in Europe at a time when an Official response was required in the second application. No response was made within the statutory period; the second application became abandoned. The Commissioner of Patents, upon a proper showing by the attorney, that the abandonment was unintentional and unavoidable, revived the second application. In the meantime, the inventor had made a third and better form of the complicated machine and he filed a third application. The third application carried on the broad invention disclosed in both of the previous applications. The second application was formally abandoned and the prosecution continued with the third application. The third application got into interference. There was a hard fought battle and the Courts finally held that the first application as filed disclosed the broad invention of the interference; that it was a constructive reduction to practice; and that the invention disclosed in this first application had never been abandoned and so this party won the interference.

We have explained that after an application is allowed and the final fee is not paid within a prescribed period of time, the application becomes forfeited and an additional period of time is allowed in which the application may be renewed by paying a new filing fee. A forfeited and renewed application comprises a constructive reduction to practice as of the original filing date of the application. This same doctrine applies to a reissue application. Where a reissue of a patent is filed, and the reissue application gets into interference on an invention disclosed in the original application, the date of constructive reduction to practice is the date of filing the original application which eventuated in the original patent.

In order to obtain the benefit of constructive reduction to practice, the application must disclose an operative machine or process. The mere fact that the actual disclosure will not work, however, is not enough to defeat constructive reduction to practice, providing the error may be corrected by the skill of the art without the requirement of invention. For example, if an invention includes in its concept the use of standard electrical apparatus and the drawings show these standard apparatus as being wrongly connected, such a disclosure will be held to be a constructive reduction to practice for the reason that anyone skilled in the art would know how to properly connect well-known and standard electrical apparatus. The defect is merely in form—not in substance.

It is not claims that control constructive reduction to practice; it is disclosure. If the original application discloses the invention, it is unimportant that the invention was not originally claimed.

Where an application was altered by the addition of a claim after it had been signed and sworn to and before it had been filed in the Patent Office, such an application was held not to be a constructive reduction to practice. The reason being that the rules of the Patent Office specifically provide that such an application will be stricken from the files. In this particular case, it was brought out that the senior party executed his application, transmitted it to his attorney in a distant city and accompanied the executed application with a claim written in his letter, which claim he requested should be typed into the application. There was sufficient space on one of the pages to permit this to be done and the attorney typed in the claim as requested by the letter, then mailed the application to the Patent Office. During the taking of testimony, these facts came to light and the Patent Office struck the application of the senior party from the files of the Patent Office and awarded invention to the junior party. This case raises a very interesting point, namely, that a situation may arise wherein neither party can obtain a valid patent to a broad, patentable invention. If in the case above-mentioned, the senior party had taken testimony to prove that he had reduced the invention to actual practice before the junior party conceived his invention and the invention of the senior party had been on sale more than two years before the defect was discovered, then the striking out of the senior party's application from the file would have left the senior party up in the air since he would have been prevented from filing a new application because of the statutory bar of public sale. The records would show that the junior party was not the first and original inventor, and, therefore, he could have no patent. Consequently, the common broad patentable subject-matter constituting the interference would go to the public.

In the case above specified, where the application was actually stricken from the file, the senior applicant requested the Court to erase the matter which had been added by the attorney at the request of the applicant and thereby restore the application to the condition when the applicant executed it. The Court declined to do this, stating that it was not in the province of the Court to change the record, and that the Court was compelled to pass upon the record as it came to it, and apply the law to the facts. Furthermore, the Court pointed out that if it undertook to correct a defective record, it would be a dangerous practice because the Court would be continually called upon to correct and change defective applications.

Code of Fair Competition for the Boiler Manufacturing Industry

Article I—Purpose

TO EFFECTUATE the policy of Title I of the National Industrial Recovery Act, the following provisions are submitted as a code of fair competition for the Boiler Manufacturing Industry, and upon approval by the President shall be the standard of fair competition for this Industry.

Article II—Definitions

The term "boiler manufacturing industry" shall be held to comprise all persons engaged in the manufacturing of all types of steel steam boilers for stationary and marine use (except boilers for locomotives and such boilers as may be specifically covered by codes approved hereafter by the President) stokers of 36 square feet of grate area and over, pulverized fuel equipment, superheaters, air preheaters, and economizers and Class One welded pressure vessels, as defined in the unfired pressure vessel section of the Boiler Code of the American Society of Mechanical Engineers, and, with the approval of the Administrator, such other affiliated groups as may request inclusion.

The term "employer" as used herein shall mean any member of the industry.

The term "employee" as used herein shall mean any person employed in any phase of the industry, however compensated.

The provisions of this Code shall become effective on the second Monday after the approval by the President.

Article III—Application

The American Boiler Manufacturers Association representing the industry hereby accepts and agrees to be bound by the following and/or other regulations established by the A.B.M.A. Committee of Industrial Recovery (duly constituted by the American Boiler Manufacturers Association in convention assembled June 5, 1933, as the agency for the preparation and administration of this Code), and approved by the President of the United States, and enforced impartially on all manufacturers in the industry whether members of this Association or not.

Article IV—Child Labor

No member of this Industry shall employ any person under 16 years of age, provided, however, that where a State law provides a higher minimum age no person below the minimum provided by such State law shall be employed in that State.

Article V—Hours

SECTION 1. (*a*) No employer shall employ, in any labor operations, any person more than 40 hours per week, five consecutive days and eight consecutive hours per day, except as provided under paragraph (*b*), provided, however, that where it is necessary to work less than 40 hours per week, the hours may be divided by agreement between the employer and the employees to a lesser number of days per week, but in no case shall the hours exceed nine per day.

(*b*) In cases of emergency production, repair or erection work that cannot be met by the employment of additional men and it becomes necessary, in order to protect life or property, to exceed the hours scheduled in (*a*), all such excess time shall be paid for at the rate of not less than one and one-half times the hourly rate for shop work and not less than double time for all repair, renewal and construction and/or erection work.

(*c*) No new apprentices shall be employed in the Industry except that the Administrator may grant the employment of such new apprentices if in his judgment the existing surplus of unemployed labor is absorbed in reasonably steady employment.

(*d*) For all other employees except executive, administrative and supervisory employees, and traveling and commission salespeople, the time worked shall not be in excess of 40 hours per week.

SEC. 2. No employee shall be employed or permitted to work for one or more employers in the industry in the aggregate in excess of the prescribed number of hours in a single week; provided, however, that if any employee works for more than one employer for an aggregate period in excess of such maximum without the connivance of any one of such employers, said employers shall not be held to have violated this paragraph.

Article VI—Wages

SECTION 1. (*a*) The minimum wage that shall be paid by any employer to any employee of the Boiler Manufacturing Industry in labor operations directly incident thereto shall be 34¢ per hour for the Southern territory and 40¢ per hour for all other portions of the United States. The Southern territory is located South of the States of Maryland, West Virginia and Kentucky, and East of the Mississippi River.

(*b*) Old or partially disabled employees, and watchmen are not included in the above labor provisions, except that they shall in no case be paid less than 80% of the above minimum, and provided that the total number of such employees shall not exceed 2% of the total number employed by any one employer, or where less than one hundred persons are employed such employer shall be entitled to two (2) employees of this class.

(*c*) The minimum wage that shall be paid by any employer to all employees, other than those covered in Section (*a*) except commission salespeople, shall be at the rate of $15.00 per week, provided, however, that office boys and girls may be paid not less than 80% of such minimum wage, but the total number of such office boys or girls shall not exceed in any calendar month 5% of the total number of all employees covered by the provisions of this paragraph (*c*) and provided further, that where a State law provides a higher minimum wage, no person shall be paid a lower wage than that required by such law, within that State.

SEC. 2. Any system of contracting shop work by which an employee undertakes to do a piece of work at a specific price and engages other employees to work for him is prohibited by this Code.

SEC. 3. The wage differentials for all operations shall be equitably readjusted, and in no case shall they be decreased. No unfair advantage shall be taken of any employee in making this code effective. Each member of the industry shall report all such readjustments to the Code Authority within 30 days of the effective date.

SEC. 4. No employer shall contract for the fabrication and/or erection of any product of this Industry with any employer or employee, except when such employer or employee agrees to comply with the labor provisions of this Code during the performance of the contract.

SEC. 5. Each employer shall post in each workshop and central notice board in his factory, Articles V and VI of this Code.

Article VII—Statutory Provisions

All employers in the Industry shall comply with the following provisions of the National Industrial Recovery Act:

1. That employees shall have the right to organize and bargain collectively through representatives of their own choosing, and shall be free from the interference, restraint or coercion of employers of labor, or their agents, in the designation of such representatives or in self-organization or in other concerted activities for the purpose of collective bargaining or other mutual aid or protection.

2. That no employee and no one seeking employment shall be required as a condition of employment to join any company union or to refrain from joining, organizing or assisting a labor organization of his own choosing; and

3. That employers shall comply with the maximum hours of labor, minimum rates of pay and other conditions of employment, approved or prescribed by the President.

Article VIII—Participation

1. Any member of the industry may participate in the endeavors of the A.B.M.A. Committee of Industrial Recovery in the preparation of any revisions of, or additions or supplements to, this Code by accepting the proper pro rata share (in the proportion of dollar billings by each in the industry to the total dollar billings of this industry or in such other manner as the A.B.M.A. Committee of Industrial Recovery may deem advisable, subject to the approval of the Administrator) of the cost and responsibility of administering this Code; provided, however, that no inequitable restriction upon membership in the Association shall at any time be imposed.

2. The Association and its members bind themselves in every way to carry out the spirit as well as the letter of this Code.

3. This Code is adopted in a spirit of fairness to all concerned, and it is the intention of the members of the industry to accord to those from whom they purchase the same treatment that they expect to receive from those to whom they sell.

Article IX—Administration

1. To facilitate the effective administration of this Code, and to provide the Administrator with requisite data as to the observance or nonobservance thereof, the A.B.M.A. Committee of Industrial Recovery is hereby designated as a Planning and Fair Practice Agency to cooperate with the Administrator in the enforcement of this Code. The Administrator may also appoint one or more representatives to serve with the Committee in an advisory capacity; such appointees to have no vote. Such Committee shall have the following powers and duties, all of which shall at all times be subject to the approval of the Administrator:

(*a*) To collect from the members of the industry the reports and data provided for in this Code, or in any supplement thereof, which may hereafter be adopted. These reports and data shall be submitted to a full-time Manager (or his Deputy) who shall be appointed by the Committee. All such reports and data shall be kept confidential by such Manager (or his Deputy) excepting insofar as may be necessary for the effective enforcement of this Code, but shall be available to the Administrator and his representatives.

(*b*) In addition to information required to be submitted to the Committee, there shall be furnished to government agencies such statistical information as the Administrator may deem necessary for the purpose recited in Section 3 (*a*) of the National Industrial Recovery Act.

(*c*) To authorize the Manager (or his Deputy) to make such investigations as in its opinion may be necessary to effectuate the proper administration of this Code.

(*d*) To make reasonable rules and regulations designed to help effectuate the purposes of the Code.

(*e*) To hear complaints and, if possible, adjust the same.

Article X—Fair Practice

1. In the conduct of its business, each member of the industry shall use a method of cost accounting which recognizes and includes all items entering into costs, as set forth in the Standard Accounting and Cost System adopted by The Machinery Builders Society, 4th Edition, revised September 1933, such system of accounting to be subject to the approval of the Administrator.

2. No member of this Industry shall sell any combination of products, except repair and replacement parts, manufactured by him, or by any owned or controlled subsidiary, at a price less than the sum of his established selling prices for all items included in such combination.

3. No member of the Industry shall make payment or allowance of rebates, refunds, credits or unearned discounts, whether in the form of money or otherwise, or extend to certain purchasers services or privileges not extended to other purchasers under like terms and conditions.

4. The settlement of old accounts for less than the full amount as a consideration for accepting a proposal is prohibited under the meaning of clause 3.

5. No member of the Industry shall make a deposit for the privilege of receiving plans and specifications and the opportunity to bid on a contract without an agreement by the issuer that such deposit will be returned to said member of the Industry when the contract has been awarded or when said plans and specifications have been returned by said member to the issuer.

6. The Committee will recommend to the Administrator forms of contract which, when approved, will be standard in all respects, except that they will not attempt to describe the equipment quoted upon. They will standardize the wording of all general conditions, warranties, terms, and deferred payments, guarantees of performance (if any), bonus and penalty clauses (if any), etc. These forms of contract and no others shall be used by the industry except in cases where Federal, State or Municipal laws necessitate otherwise.

7. No member of the industry shall make a guarantee of maintenance because of the impossibility of defining and maintaining the conditions under which such a guarantee can honestly be made. Guarantees of performance are permissible when conditions, under which such guarantees are to be met, are definitely stated. Guarantees of workmanship and material are quite proper. No member of the industry shall promise a better performance or make a higher guarantee than his previous experience leads him to believe he can obtain.

8. No member of the industry shall accept a contract containing a penalty clause either for performance of the apparatus sold or for time of delivery, unless the contract shall also contain a clause providing a bonus to the contractor at the same rate as the rate of penalty, except in cases where Federal, State or Municipal laws necessitate otherwise.

9. No member of the industry shall accept a contract containing a clause providing for liquidated damages, except in cases where Federal, State or Municipal laws necessitate otherwise.

10. Where purchaser's specifications include a bonus clause for performance, efficiency, etc., in excess of that guaranteed, no member of the industry shall deduct from the price any bonus or portion thereof which he anticipates will be earned by reason of his obtaining a better performance or efficiency than that guaranteed.

11. Where purchaser's specifications include a penalty clause for performance, efficiency, etc., less than that guaranteed, no member of the industry shall make a guarantee in excess of that which he expects to obtain anticipating the acceptance of a penalty as a basis for reducing the cost to the purchaser.

12. No member of the industry shall circulate threats of suit for infringement of patents or trade marks among cus-

tomers of a competitor not in good faith but for the purpose of harassing and intimidating customers.

13. No member of the industry shall disseminate false or misleading information relative to competitor's products, selling prices, credit standing, ability to perform work, or labor conditions among competitor's employees.

14. No member of the industry shall make false or misleading statements as to time of delivery, performance, facilities, equipment or ability to perform work.

15. No member of the industry shall attempt to induce the breach or abandonment of any contract between a manufacturer and his customer.

16. No member of the industry shall be a party to commercial bribery in any form or under any condition.

17. No member of the industry shall enter into a written or oral agreement with any person that one or more clauses of the contract or the specification will not be enforced, thereby receiving an unfair advantage over competitors.

18. No member of the industry shall purchase patents from customers, their officers, engineers or employees, for the purpose of influencing sales to such customers.

19. No member of this industry shall cause or permit any conduct by any one of his employees or agents which would constitute a violation of this Code.

Article XI—Monopolies

No provision in this Code shall be interpreted or applied in such a manner as to:

1. Promote or permit monopolies or monopolistic practices;
2. Permit or encourage unfair competition;
3. Eliminate, discriminate against or oppress small enterprises.

Article XII—Rights of President

This Code is hereby made expressly subject to the right of the President, pursuant to Section 10(*b*) of the National Industrial Recovery Act, from time to time to cancel or modify any order, approval license, rule or regulation issued under Title I of said Act, and specifically, but without limitation, to the right of the President to cancel or modify his approval of this Code or any conditions imposed by him upon such approval.

Article XIII—Amendments

Such of the provisions of this Code as are not required to be included therein by the National Industrial Recovery Act may, with the approval of the President, be modified or eliminated upon the application of the A.B.M.A. Committee of Industrial Recovery as changes in circumstances or experience may indicate. It is contemplated that from time to time supplementary provisions to this Code or additional Codes will be submitted by the A.B.M.A. Committee of Industrial Recovery for the approval of the President to further effectuate the purposes and policies of Title I of the National Industrial Recovery Act consistent with the provisions hereof.

The Code, in the form as here presented was approved by President Roosevelt on October 3, 1933.

Cleaning Illinois Coal

Mechanical cleaning of coal in Illinois was first undertaken in 1870 and the practice grew for the next forty years. However, from 1909 to 1931 it steadily declined for the following reasons: new beds of clean coal were opened in southern Illinois; it was found difficult to produce a washed coal low enough in sulphur for metallurgical coke; the development of screening practice to produce closely sized products which are more efficient than unsized; and the development of mechanical stokers and pulverizing equipment which burn successfully coals higher in ash than was possible in the old hand-fired plants.

Within the past two years, however, there has been renewed interest in cleaning Illinois coal principally because of the consumer demand for coal of definite specifications to serve particular purposes and because of smoke abatement agitation on the part of municipalities. Moreover, the increased use of mechanical loading equipment has tended to cause an increase in ash and sulphur content that, in the finer sizes cannot be hand-picked effectively.

In view of this a broad investigation of the washability of Illinois coal was undertaken in the summer of 1931 by the Engineering Experiment Station of the University of Illinois and the results are published in Bulletin No. 258, recently released.

This investigation, based on a study of 70 samples, indicated that coal from a majority of the workable beds of the state presents a simple or only moderately difficult cleaning problem and that at many of the mines a low-sulphur coal can be prepared for the market equal to, or better than, the imported coals. Whether coal from any particular mine could be cleaned and offered at a competitive price with imported coal is an economic problem not covered by this investigation.

Naval Architects to Discuss Boiler Problems

The program for the annual meeting of the Society of Naval Architects and Marine Engineers, to be held at the Engineering Societies Building, New York, November 16th and 17th, will include three papers of particular interest to steam engineers. They are "Water Circulation and Gas Path in Naval Boilers" by Rear Admiral Samuel M. Robinson, U.S.N., "Water Conditioning and Related Problems of Marine Boiler Operation" by Dr. A. C. Purdy, and "Diesel versus Steam Drive for Cargo Ships" by Louis R. Ford.

Better Lighting Cuts Accidents in Detroit

The better lighting campaign for municipalities, now being carried on by the utilities, has many commendable objectives. One in particular is the reduction in street accidents. Experience in Detroit is pertinent. According to Louis J. Schrenk Superintendent of the Public Lighting Commission, that city had a marked increase in street fatalities during a period when the lighting was curtailed approximately one-third for reasons of economy. During the first four months of 1931, before the lighting was curtailed, there were 32 day traffic fatalities and 72 night fatalities, whereas for the same period of 1932, when lighting was curtailed the night fatalities jumped to 93. This increase resulted in a restoration of the former street-lighting schedule.

H. H. Blakeslee, formerly assistant manager of the New Orleans office of the General Electric Company, has been appointed manager of that office to succeed B. Willard, who is retiring on pension.

J. W. Hicklin, heretofore manager of the Richmond office of the company, has been made manager of the Baltimore office, succeeding G. H. Gilbert.

The Northern Equipment Company, Erie, Pa., announces the appointment of The C. J. Gaskell Company as Memphis Tenn., representatives for Copes feed water regulators, differential valves, pump governors and allied equipment. Mr. Gaskell had been associated with the former Copes representatives in the Memphis territory for a number of years.

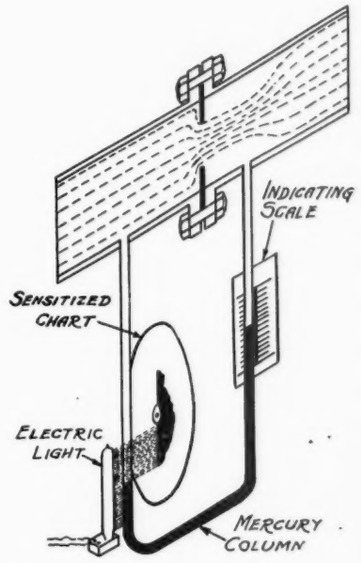
NEW EQUIPMENT

of interest to steam plant engineers

Recording Flow Meter

The Foto-Flo Meter is manufactured and sold by The Trimount Instrument Company, 332 So. La Salle Street, Chicago, Illinois.

The principle used in the Foto-Flo Meter is that of a common mercury manometer actuated by differential pressure produced by means of an orifice installed in the flow line. The direct method of recording used in this meter eliminates the necessity for any moving parts. When the differential pressure produced by the flow of a fluid through an orifice is applied to a manometer, which is a U-shaped glass tube partially filled with



mercury, the mercury will drop on the leg of the "U" tube which is connected to the high pressure side of the differential, and rise in that which is connected to the low pressure side. The resulting difference in mercury levels will be directly proportional to the differential pressure as well as to the rate of flow of the liquid through the orifice. A light placed behind one leg of the manometer causes the varying levels of the liquid therein to be recorded on the sensitized surface of the recording chart.

The Foto-Flo Meter has a wide latitude of application. It is used to measure steam production, boiler feedwater, departmental distribution of gas, steam, air and water. It also has many other special applications.

Improved Bucket Trap

A series of improved inverted bucket traps has been announced by the Strong Carlisle & Hammond Company of Cleveland. This includes semi-steel constructions for low and medium pressures and higher pressures, and for superheat services. The principal improvements are in the method of retaining the seat in place and in the anti-balancing device.

The seat is inserted by a special process into a steel seat holder which is forced against the machined (gasket) surface of the cover by the Fulcrum Bracket, which in turn is held by special alloy heat treated studs. By removing two nuts the bucket may be lifted off and seat holder removed.

In the anti-balancing device the lever is fitted with a valve which replaces the air vent in the bucket. This valve is arranged with a small opening which allows air and gases to escape from the bucket while the trap is filling. When the trap reaches the point of discharge where balancing usually occurs in inverted bucket traps, the larger valve is automatically opened, permitting the quantity of air to escape suddenly from the bucket, to be replaced by sufficient water to over-balance the bucket and open the main trap discharge valve instantly.

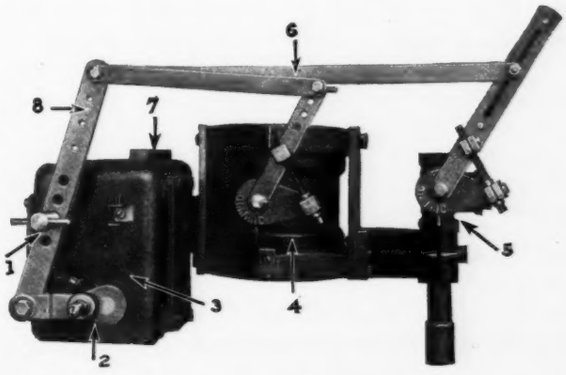
New Two Position Motor Operated Controller

To meet the demand for a sturdy, inexpensive controller of the two position type to operate one or more valves as a unit, a damper or a rheostat, the Automatic Temperature Control Company, Inc., Philadelphia, Pa., has added to its line of motor operated controllers a new unit known as Type 2, which has sufficient power to handle an air valve up to 4 in. size in combination with a $^1/_2$ in. fuel oil valve or to handle two valves up to 4 in. as a unit on low pressure gas and air.

Where furnace atmosphere is important, valves having similar characteristics are provided, each equipped with micrometer screw adjustment for minimum setting and with index and dial plate to permit readily duplicating previous settings. Maximum settings for both fuel and air valves can be obtained by adjusting the connecting links (6) where attached to the valve levers, and where attached to the main operating lever (8).

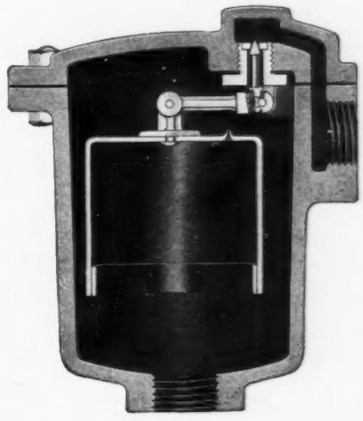
A feature which is standard with Type 2 Controller is the ability to quickly remove the fulcrum stud (1), thus permitting the attendant to manually move the main operating lever (8) with attached valves to any desired position. This feature is a convenience when starting up a furnace and it also eliminates the expense of by-pass piping and valves for the air line.

Where full pipe line capacity is required, and tight shut-off is essential, Type 2 Controller can be supplied to operate valves of globe body type in sizes up to 3 in., for pressures up to 250 pounds per square inch. Where the medium is at lower pressures, Type 2 Controller has sufficient power to handle larger valves of globe body type. These valves can be provided with an adjustment feature permitting any desired minimum setting up to 50 per cent of valve capacity.



Large Volume Trap

The Jas. P. Marsh Corporation, 2073 Southport Avenue, Chicago, has brought out a line of inverted bucket traps specially adapted for services where considerable columns of condensate can be handled.



The trap is self-venting. The motive element being an inverted seamless open bucket operating through a cast brass lever arm to open and close the swivel valve pin.

The bucket is of seamless copper and the levers and clevises are of cast bronze. All piping connections are made to the body which permits removal of the trap without disturbing the piping. The entire operating mechanism lifts out with the trap cover thus making all traps easily accessible.

BOOKS FOR ENGINEERS

1—Stop That Smoke!

By Henry Obermeyer

289 pages Price $2.50

The smoke nuisance is still with us. Its damages, its dangers to life and property, its wastes, its ugliness—these are all still with us. And the toll of cost is tremendous. The author of this book sets forth the present condition conservatively, but with an overwhelming body of evidence. And he shows what has been done and what can be done to abate this nuisance.

Stop That Smoke! will appeal to all civic agencies concerned with this problem. Its proposals are practical and specific. It will appeal no less to every creator of smoke, whether industrialist or householder, because it supplies technical hints on preventive measures.

2—Draft and Capacity of Chimneys

By J. G. Mingle

339 pages Illustrated Price $3.50

The most authoritative book ever published on the subject of draft and chimneys. The subject matter has been developed primarily from a theoretical standpoint and then amplified by experimental data gleaned from actual practice.

The author observes that draft, even to the expert, frequently contains an element of mystery, and that there is often a great deal of confusion and misconception on the subject. A careful study of this book will give a thorough and practical knowledge of this important subject. The book is profusely illustrated with graphs and charts. Many valuable tables are included and the index has been prepared for ready reference.

3—Steam Tables and Mollier Diagram

By Joseph H. Keenan

Price $2.00

These new Steam Tables, extending to a pressure of 3500 lb. per sq. in. and a temperature of 1000 deg. fahr., were developed from the latest experimental data secured by investigators in laboratories of Europe and those of the United States. The Symbols used in this work are taken from the latest test prepared by the A. S. A. Sub-Committee for Heat and Thermodynamics. A large copy of the new Mollier diagram (23" x 34") is also included.

4—Finding and Stopping Waste in Modern Boiler Rooms

808 Pages Price $3.00

This well-known Cochrane reference book has been revised and enlarged. New matter has been introduced in the section on Fuels, Combustion and Heat Absorption, and considerable material has been added on the subjects of steam and water measurements, water treatment and testing. As a handbook on these subjects, this volume is eminently practical and useful. Every steam plant engineer should have a copy.

5—Problems in Human Engineering

By F. Alexander Magoun

585 pages Price $2.60

Here is a real case book in Human Engineering, built around fifty typical difficulties and emergencies that business men have actually had to face. The questions are those that confront men in all ranges of business success, involving relations with superiors, equals, competitors, inferiors, customers, labor and the opposite sex. Almost every personality trait that can help or hinder a man at work is brought into the limelight of discussion.

Following the brief statement of the problem the reader finds a group of the actual answers that students in the Humanics class at the Massachusetts Institute of Technology which is being conducted by Professor Magoun worked out and handed in. Good and bad, pro and con, they have been selected to preserve the controversial nature which makes this problem book so stimulating.

6—Combustion in the Power Plant (A Coal Burner's Manual)

By T. A. Marsh

255 Pages Price $2.00

The author's discussion of coals and combustion is simple and understandable. His consideration of equipment—stokers, boilers, furnaces, fans and auxiliaries—is thoroughly practical. He tells how to select a stoker for the best available coal; how to design furnaces and arches; how to analyze draft problems and design chimneys, gas flues and boiler passes; how to purchase coal and calculate steam costs. He gives to every phase of his subject a practical interpretation that makes this book of exceptional value to men actually identified with steam plant design and operation.

7—Symposium on Steel Castings

254 Pages Price $1.00

The presentation and publication of the ten extensive technical papers comprising the Symposium on Steel Castings have been sponsored jointly by the American Foundrymen's Association and the American Society for Testing Materials, the chief purpose being to provide the engineering profession with authoritative information on the properties of steel castings. Carbon-steel and alloy-steel castings are covered.

Extensive oral and written discussion adds to the value of the papers, presenting a broader view of the subjects. Diagrams, charts and tables have been extensively used by the authors to enable a quick and clear presentation of the data.

8—Pulverized Fuel Firing

By Sydney H. North

204 Pages Illustrated Price $2.25

The author of this book, an Englishman, briefly reviews the history of pulverized fuel as a prelude to a discussion of its development to the present day. Contemporary designs of furnaces, burners, feeders, pulverizing mills, driers, dust collectors, etc., are described and illustrated, as are actual installations in America and Europe which exemplify the trends of practice. Chapters are devoted to the combustion of pulverized fuel and its use in connection with Lancashire boilers, marine boilers and in metallurgical furnaces.

9—Steam Power Plant Engineering

By Louis Allen Harding

777 pages 6 x 9 Price $10.00

This book, a complete revision of Vol. II of "Mechanical Equipment of Buildings," the publication of which has now been discontinued, comprehensively covers the major problems involved in the design of power plant apparatus, the rating of the apparatus, their co-relation in the scheme of power plant engineering, and the economic factors involved in their selection.

Beginning logically with a discussion of fuels and combustion, the author proceeds with the treatment of boilers, furnaces, stokers, pulverizers, oil burners, superheaters, desuperheaters, resuperheaters, economizers, air preheaters, feed-water heaters, deaerating heaters, evaporators, water purifiers, pumps, steam engines, turbines, regenerators, reheaters, condensers, cooling towers, pipes, fittings, valves, heat coverings, accessories, etc.

The information contained in this book is thoroughly up-to-date and in accord with modern practices. It is written by an engineer of wide experience and should prove of value to any engineer whose work and interests lie in the steam power plant field.

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EQUIPMENT SALES

Boiler, Stoker, Pulverized Fuel

As reported by equipment manufacturers of the Department of Commerce, Bureau of the Census.

Boiler Sales

Orders for 102 water-tube and h.r.t. boilers were placed in Sept.

	Number	Square Feet
September, 1933	102	296,234
September, 1932	58	310,141
January to September (inclusive, 1933)	737	2,262,154
Same period, 1932	497	1,700,376

NEW ORDERS, BY KIND, PLACED IN SEPTEMBER, 1932–1933

Kind	September, 1932		September, 1933	
	Number	Square Feet	Number	Square Feet
Stationary:				
Water tube	39	278,865	53	233,473
Horizontal return tubular	19	31,276	49	62,761
	58	310,141	102	296,234

Mechanical Stoker Sales

Orders for 173 stokers, Class 4,* totaling 28,742 hp. were placed in September by 42 manufacturers.

	Installed under			
	Fire-tube Boilers		Water-tube Boilers	
	No.	Horsepower	No.	Horsepower
September, 1933	146	18,324	27	10,418
September, 1932	119	14,430	47	14,709
January to September (inclusive, 1933)	769	98,815	326	121,265
Same period, 1932	667	87,227	314	121,815

* Capacity over 300 lb. of coal per hr.

Pulverized Fuel Equipment Sales

Orders for 25 pulverizers with a total capacity of 126,100 lb. per hr. were placed in September.

STORAGE SYSTEM

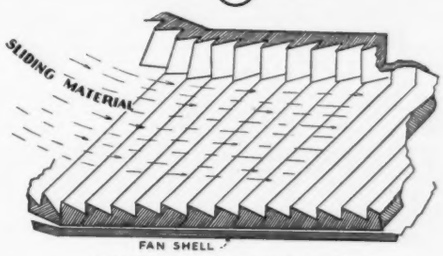
	Pulverizers				Water-tube Boilers		
	Total number	No. for new boilers, furnaces and kilns	No. for existing boilers	Total capacity lb. coal per hour for contract	Number	Total sq. ft. steam-generating surface	Total lb. steam per hour equivalent
September, 1933	..	..	..	.....	..	.....	.....
September, 1932	..	..	..	.....	..	.....	.....
January to September (inclusive, 1933)	6	4	2	220,000	4	109,432	1,445,000
Same period, 1932	5	1	4	11,250	5	17,400	110,500

DIRECT FIRED OR UNIT SYSTEM

	Pulverizers				Water-tube Boilers		
September, 1933	23	12	11	123,100	18	114,828	1,141,100
September, 1932	3	2	1	5,750	3	10,110	53,500
January to September (inclusive, 1933)	77	54	23	434,440	62	409,398	3,914,060
Same period, 1932	55	34	21	541,338	50	261,804	2,308,960
					Fire-tube Boilers		
September, 1933	2	..	2	3,000	2	3,250	27,500
September, 1932	..	..	..	.....	..	.....	.....
January to September (inclusive, 1933)	14	3	11	16,200	15	23,110	142,940
Same period, 1932	13	2	11	13,300	13	20,310	114,650

SERRA LINING

TRADE (B) MARK



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A Wear-Resisting Lining for *Induced draft fan casings, cyclones, chutes, pipes, and any surface subject to abrasive wear*

Serra Lining greatly extends the life of fan casings and other surfaces subject to wear by abrasive materials such as coal, ash, dust, sand, cement, etc. It prevents sliding of the material over the surface of the lining, and as soon as the serrations are filled with the material, a self-renewing, wear-resisting lining is formed.

Serra Lining can be furnished in cast iron, or pressed steel in widths up to 48 in. It is inexpensive and easily installed.

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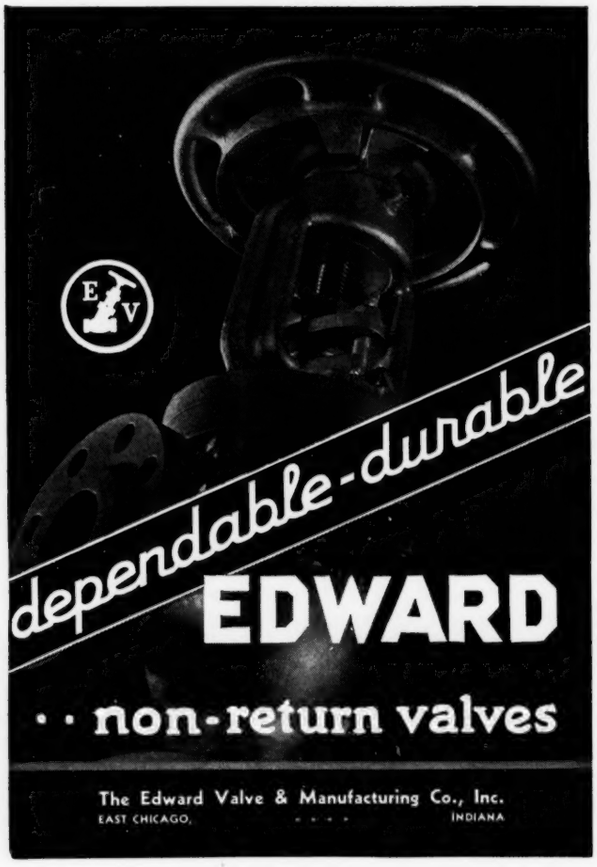

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•

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Combustion Publishing Company, Inc. (Book Department)..... 38
Edward Valve & Manufacturing Company 40
Garde Equipment Company 39
Globe Steel Tubes Company 39
Ingersoll-Rand Company..Third Cover
National Aluminate Corporation .. 6
Steel and Tubes, Inc. 40
Superheater Company, The 2